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WASTE WATER TREATMENT. AERATION OF WASTE WATER BY OXYGEN

NATO Committee on the Challenges of Modern Society
Brussels, Belgium

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Oxygen enriched air or industrial oxygen appear to be particularly suitable for waste water treatment in the following cases: Wastes with high organic loads of varying concentration, wastes with easily volatile components, tending to emit odors, overloading of existing plants, where the local conditions do not permit any extension of the area. There are still a number of disadvantages and questions still to be examined.

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Aeration of Waste Water by Oxygen

Aeration des Eaux usees à l'aide d'Oxygen

PROCEEDINGS
COMPTE RENDU

Seminar Wuppertal/Federal Republic of Germany
Seminaire Wuppertal/Republique Federale d'Allemagne

10th/11th January 1973 - 10^{e}/11^{e} janvier 1973

Within the framework of the CCMS - Pilot Study on "Advanced sewage treatment" the Federal Republic of Germany has undertaken to carry out investigations on the subject"Aeration of waste water by oxygen" as one of the co-pilot studies.

The investigations at semitechnical level were carried out in the waste water treatment plant of the Wupperverband at Wuppertal-Buchenhofen.

A report on the results as well as on those of semilar tests in the Federal Republic of Germany, in the United Kingdom and in France were presented anddiscussed on a CCMS-expert-workshop at 10th and 11th January 1973 in Wuppertal.

The present publication gives the proceedings of that workshop.

Bonn, September 1973

CONTENS / CONTENU

	Page
Adress of the Minister of the Interior H.-D.Genscher	2
The use of industrial oxygen in the activated sludge process by Prof.Dr.Dr.h.c.H.Liebmann † and Dr.K.Scherb,Munich	5
The Purification of highly polluted waste in a test plant,using pure oxygen by Dipl.-Ing.W.Hegemann,Wuppertal	18
Biological purification of waste water using oxygen by Dr.K.Mack,Wuppertal	43
Research into the use of oxygen in sewage treatment in the United Kingdom by A.H.Goodman,London	57
Report on the test carried out at the Munich-Grosslappen sewage works,using the oxygen aeration process by Oberbaudirektor F.Karnovsky,Munich	66
Preliminary results of parallel test with fine bubble aeration and oxygenation by the Lindox process by Dr.K.Scherb,Munich	77
L'epuration biologique des eaux a l'aide d'oxygen pur ou d'air enrichi,travaux français de D.Larre,Paris	9o
Étude de l'epuration biologique avec aeration a l'air enrichi en oxygen de D.Larre,Paris	94
Summary and prospects by Prof.Dr.-Ing.W.Bischofsberger,Munich	1oo

ADDRESS
OF THE MINISTER OF THE INTERIOR -
H.-D. GENSCHER

Address of the Minister of the Interior - H.-D. Genscher

Ladies and Gentlemen,

in my capacity as the minister responsible for environmental questions in this Federal Government, I am pleased to welcome you here in Wuppertal.

Being a particular friend of this town, I am very pleased that the expert meeting of the NATO CCMS has been convened here.

The Wupperverband has indeed deserved well of water management in the river basin of the Wupper and is one of those water management associations which are doing exemplary work also on an international level. Thus it was only natural to charge the Wupperverband with the testing of new processes for the purification of effluents.

The Committee on the Challenges of Modern Society which was established within the North Atlantic Council in 1969 on the initiative of the United States has given the North Atlantic Treaty a "third dimension" of practical international cooperation and mutual assistance in questions of environmental interest. As far as the Federal Government is concerned, the questions of international cooperation in the field of environmental policy are given high priority.

This became evident through the invitation to the first European Conference of Ministers Responsible for the Environment, held in Bonn in autumn 1972, as well as through the unrestricted cooperation of the Federal Republic of Germany in all international bodies, including the UN Conference on the Human Environment in Stockholm.

No country is able to tackle its environmental problems separately and without cocperation with other countries.

This does not only apply to all those fields where states adjoining certain rivers or watercourses are forced to cooperate.

I am saying this also in view of the determination of the

Federal Government which is making efforts to promote the development of international standards and regulations for the protection of our environment, since it does not want to allow any new trade barriers to develop between the industrialized countries of the world, nor any new distortions of economic competition. Environmental protection belongs to the great challenges to be met in particular by the industrialized countries.

This meeting gives evidence of the necessity and reality of international cooperation. Not only experts from the Federal Republic of Germany but also from the United States, from France, Great Britain, the Netherlands and Belgium have come together for the present event.

Thanks to its realistic and pragmatic way of working, the NATO CCMS has in the last few years achieved valuable results in important fields of environmental protection also for the Federal Republic of Germany. I should like to cite as an example the Three-City Study undertaken in Frankfurt, Ankara and St. Louis, and aiming at the development of an optimum approach to the solution of air pollution problems in urban agglomerations.

For the time being, evaluation criteria are available for 6 pollutants. They have been accepted throughout the world and allow more systematic and more specific improvement of air quality, particularly in large cities, thus providing an important basis for emission control also in our country.

Another example is the agreement, signed in November 1972, on the exchange of experience in the field of the development of low-pollution engines for motor vehicles.

To these examples I could add further examples from the fields of water pollution control and water resources planning, such as the establishment of a mathematical model relating to water pollution in the North Sea or measures against oil pollution.

I should like to express the wish that this expert meeting of the NATO Committee on the Challenges of Modern Society at Wuppertal will have successful discussions.

THE USE OF INDUSTRIAL OXYGEN IN THE ACTIVATED SLUDGE PROCESS

by

Professor Dr.Dr.h.c. H. Liebmann †

and

Dr. K. Scherb

Munich

1. Introduction

In future, research work aiming at the development of optimum waste water treatment deserves particular attention. This also includes the application of industrial oxygen in the activated sludge process which in the last few years has come into discussion above all via the United States. The investigations carried out in the United States are described in research reports with an optimistic outlook on the application of industrial oxygen (Albertson, Whirter, Robinson and Vahldieck 1970).

The use of industrial oxygen for the treatment of waste water as such is nothing new. This problem was subject to investigations as early as several decades ago (e.g. Okun, 1949, and others). Hitherto, however, the use of industrial oxygen did not appear to be very practicable. The relatively high costs of oxygen supply were considered as one of the drawbacks of this method. Differing views were expressed with regard to process technology. While some researchers expected certain advantages, others did not see any progress in this technique. The major problem was the development of processes ensuring optimum utilization of the oxygen in the purification process. In this respect, some progress was made only in the last few years. The investigations showed that it is possible under certain conditions to considerably increase oxygen utilization.

In the Unox process developed by Union Carbide, USA, more than 90 per cent of the oxygen fed to the plant were dissolved. Subsequently, a large-scale test was initiated at the Batavia sewage works, New York. Recently several sewage works have been constructed which make use of industrial oxygen. There is as yet too little adequate information about the results obtained in these plants to establish under which conditions the process may be of advantage.

2. Processes for the aeration of activated sludge, using industrial oxygen

A number of systems using industrial oxygen are being discussed. In addition to Union Carbide, other firms have also started working in this field, for example Air Products (USA), Airco (USA), Cosmodyne (USA), FMC (USA), Degremont (France) and Linde AG (Germany).

The system developed by Union Carbide consists of a series of airtight sealed tanks. Oxygen is introduced into the gas chamber of the first tank at low pressure (Figure 1). The oxygen is then sucked off by means of compressors mounted on the cover of the tanks and introduced into the water-sludge mixture via the hollow shaft of an agitator. The oxygen is diffused through perforated pipes or filter units and is at the same time distributed in the water-sludge mixture by stirring paddles; fixed paddles ensure thorough mixing and renewal of interfaces.

Since in the water-sludge mixture, oxygen is utilized continuously, and carbon dioxide is produced by the biological processes, the oxygen content decreases from stage to stage, and in the last stage is only about 40 - 50 per cent. An exhaust pipe allows the waste gas to escape from the last tank into the atmosphere.

In March 1972, a semi-technical test plant from Union Carbide, consisting of 3 stages, each with a capacity of 270 l, was started up by the Wupperverband at the Wuppertal Sewage Works and another such plant by Bayer AG, while on the site of the municipal sewage works of Munich a Union Carbide pilot plant was put into operation in October 1972. This plant consists of 4 stages with a total capacity of more than 11 m^3.

A 1-stage process using industrial oxygen was developed by Cosmodyne (Figure 2). In the Simplox process developed by Cosmodyne, industrial oxygen is introduced into the anterior part of the aeration tank by means of a diffuser. The gas accumulating above the activated sludge mixture is subse-

quently sucked off by means of a compressor mounted on the cover of the unit and is then introduced into the aeration tank again via filter units.

In the Airco system, oxygen is introduced into a system of pipes (Figure 3). Subsequently, oxygen enriched activated sludge is transported into a mixing tank together with return sludge from the final settling tank and the inflowing waste water and from there is fed into a reaction pipe.

In Germany, the utilization of industrial oxygen in the activated sludge process has been tested for some time now by Linde AG, Werksgruppe Tieftemperatur und Verfahrenstechnik, Munich. Mobile pilot plants were developed. The first stationary unit with a working capacity of 20 m^3 was established at the test site of the Bayerische Biologische Versuchsanstalt at Munich/Großlappen (Figures 4 and 5). The oxygen fed to the aeration tank by means of a compressor, passes finely porous filter units (pipe aerators according to Schuhmacher) at ground level and then ascends to the surface of the water-sludge mixture.

For stirring the water-sludge mixture, an agitator in the form of a paddle is used which is moved in the direction opposite to the oxygen stream. The oxygen not dissolved during the passage through the activated sludge accumulates above the surface level in the aeration tank and is sucked off and introduced into the water-sludge mixture again by means of a compressor. A certain part of the gas stream containing CO_2, N_2, etc., is allowed to escape. In large-scale plants, this part of the gas stream may be fed to an air-separation plant and treated there. Usually the Lindox plant is designed as a one- or multi-stage unit.

These were a few examples for treatment processes using oxygen.

The oxygen is usually fed to the test units from an oxygen tank. Sewage plant projects, particularly larger plants, would, in the light of present knowledge, have to be equipped with plants for generating oxygen. Oxygen might be supplied

from truck tanks in the case of smaller plants, and in the case of larger plants only under special circumstances or when bottlenecks occur. Oxygen may be produced by low-temperature process or by adsorption process. The adsorption process is above all suitable for plants treating the sewage of less than 1 million inhabitants, i.e. for plants using not less than 100 t O_2/day.

3. Energy demand in the oxygen aeration process

The energy required for producing oxygen in cryogenic plants is first of all dependent on the size of the plant and the required purity of the product. According to information from Linde AG, specific energy values of 0.4 kWh per kg of pure (99 per cent) oxygen may be required in medium-size plants (about 100 t O_2/day), while in large-scale plants (about 1000 t O_2/day) approximately 0.32 kWh/kg of oxygen are necessary. If the required degree of purity is about 80 per cent, an energy demand of about 0.3 kWh/kg oxygen will have to be expected. The oxygen must be fed to the water-sludge mixture by means of corresponding equipment, such as compressors and stirrers. The energy required for this operation varies between 0.2 and 0.4 kWh/kg oxygen, depending on the process employed.

4. Particular features of oxygen aeration as compared with the conventional aeration process

The oxygen aeration process is not fundamentally different from the conventional aeration process. The oxygen is merely introduced into the water-sludge mixture in pure form and not together with the other components of the air. More than 90 per cent of the oxygen used can be utilized, the degree of effectiveness of oxygen aeration is in this respect significantly higher than that of the conventional processes.

This is also due to the fact, that the transport velocity of pure oxygen is higher than that of air. If pure oxygen instead of air is available, the partial pressure of oxygen is almost 4.8 times higher. This implies an increase in oxygen concentration at the point of application beyond the values achieved with air. At the same time, however, it should be taken into consideration that - with the oxygen aeration process - this high degree of effectiveness is not the only decisive factor. The water-sludge mixture must also be stirred adequately, thus special stirring equipment is usually required.

One of the characteristics of the oxygen aeration process is the high oxygen content in the aeration tank. In the oxygen aeration process, an increase in oxygen content from 2 mg/l - the usual oxygen concentration of conventional plants - to about 10 mg/l, produces but a slight increase in energy consumption while on the other hand, favourable conditions of degradation can also be ensured with unusually high sludge concentrations and sludge loads.

It was stated in various reports, that the specific characteristics of the activated sludge yielded in the oxygen aeration process permit operating the activated sludge tank with unusually high sludge concentrations. The improved sludge characteristics as against conventional processes are particularly emphasized by Union Carbide on the basis of the results of tests conducted at the Batavia Sewage Works. Doubtless, this is of advantage with regard to process technology: the sludge concentration in the activated sludge tank could be increased. This would mean that smaller aeration tanks could be used than in the conventional process.

Another point emphasized by several authors is the advantage of reduced amounts of excess sludge formed in multi-stage plants. This effect is - at least with multi-stage plants - partly due to the somewhat more marked mineralisation taking place in the last stage. It is also known from the conventional process that smaller amounts of excess sludge are

produced in multi-stage systems than in one-stage tanks.

It would appear that the oxygen aeration process provides reliable treatment of industrial wastes with high organic load. With waste waters tending to evolve unpleasant odours, the use of pure oxygen may even be particularly favourable, since the small volume of waste gas produced can be easily controlled. The high oxygen concentration in the water-sludge mixture is also of advantage with regard to variations of load and peak influents with high organic pollution loads; the purification capacity will become less sensitive, since an adequate oxygen content is maintained at all operating stages. Moreover, by covering the biological stage, any formation of ice in the aeration system and any contamination of the atmosphere with germs are almost excluded.

These were some of the aspects which have been discussed in connection with the use of industrial oxygen.

In the oxygen aeration process, specific installations are required in addition to the conventional ones. On the other hand, the lower amount of gas needed is of advantage in view of equipment requirements.

The safety regulations with regard to the handling of oxygen - which are in common use in industry - must, of course, also be observed in this case.

Tests which have been initiated by several bodies will contribute to elucidate the conditions of oxygen aeration. Parallel tests with conventional processes deserve particular attention. In the tests which were started in Munich/ Großlappen in summer 1972, attention will be focused on the parallel test, using conventional processes. Two plants of equal size and load are in operation. They are fed with municipal waste and in further tests with specific industrial effluents.

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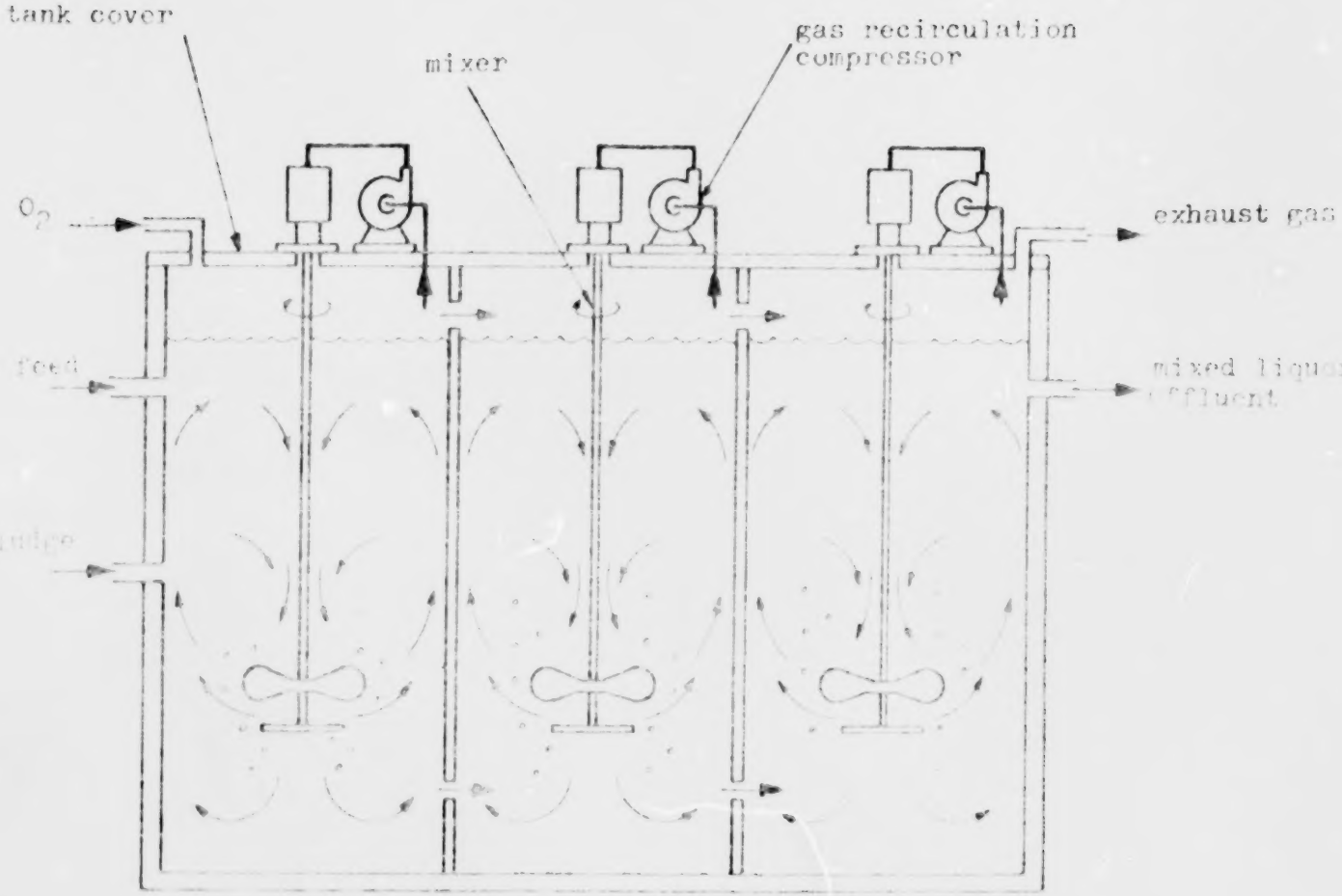


Fig. 4 Schematic Diagram of the Unox - System

Fig. 2 Simplox - System [Cosmodyne]

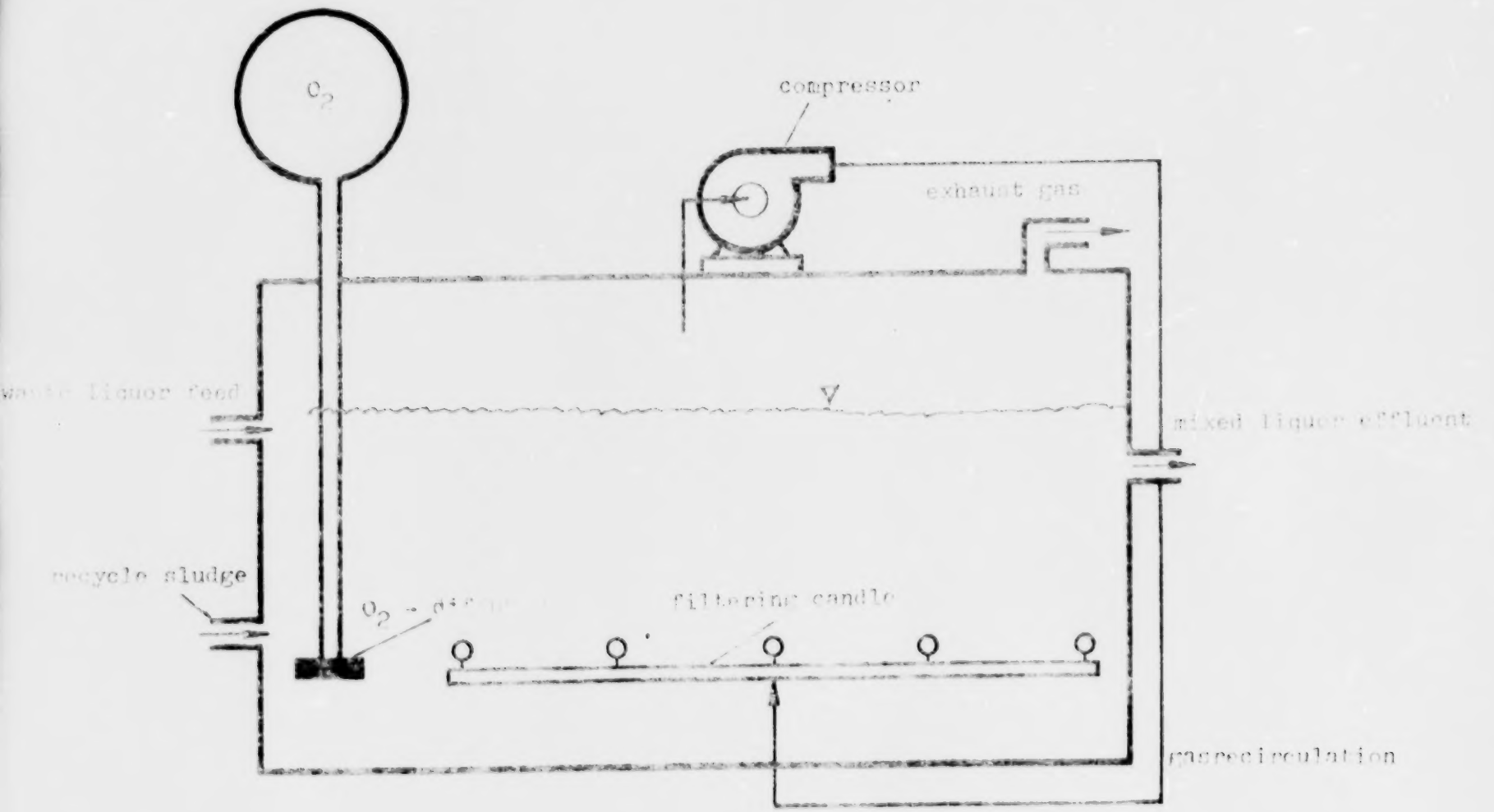


Fig. 3 AIRCO - SYSTEM

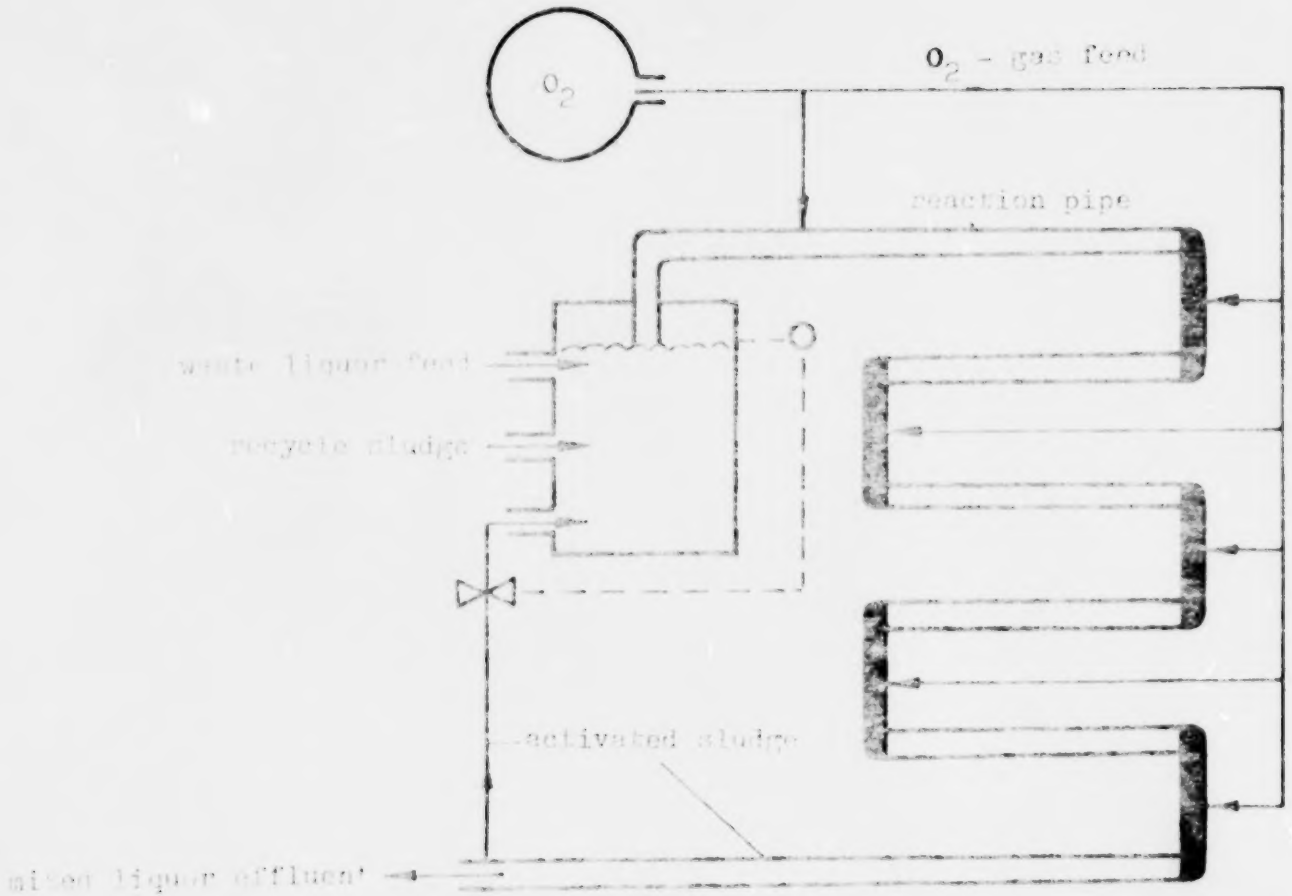
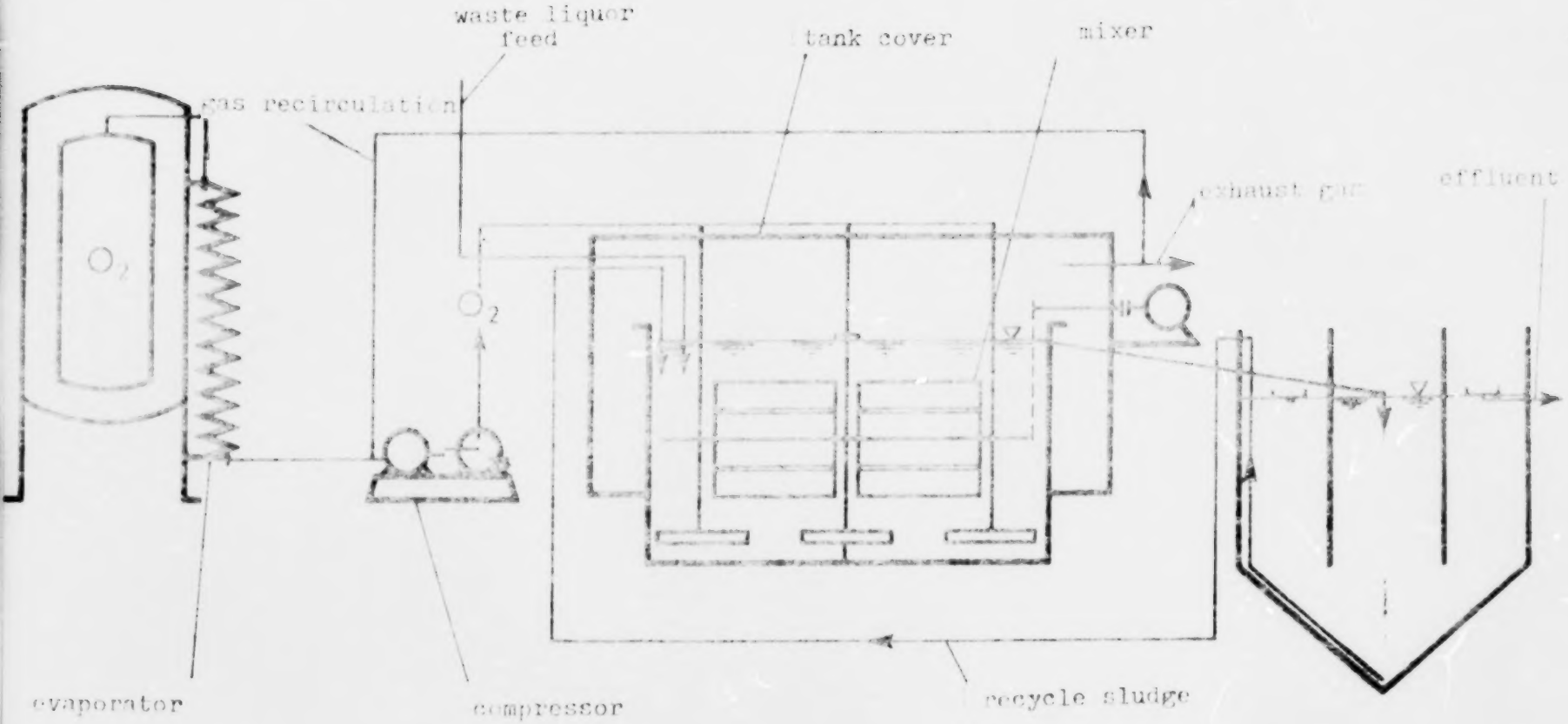


Fig. 4 LINDOX - SYSTEM



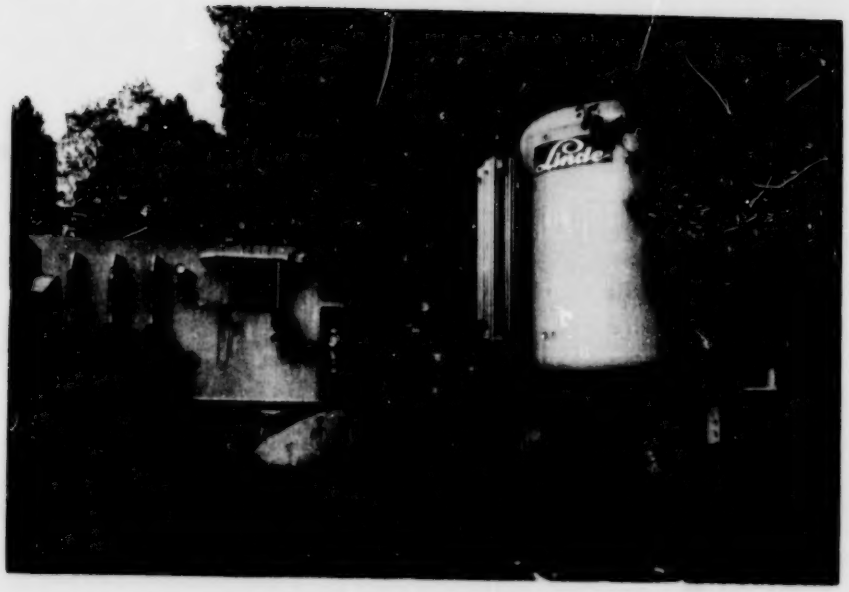


Fig. 5 The LINDOX - Testplant in the water pollution research station at Munich - Großlappen

THE PURIFICATION OF HIGHLY POLLUTED WASTE IN A TEST PLANT, USING PURE OXYGEN

by

Dipl.-Ing. W. Hegemann
Wuppertal

1. Introduction

In the waste water treatment plant of the Wupperverband at Wuppertal-Buchenhofen, the sewage of about 350 000 inhabitants of Wuppertal and from the industrial plants of this drainage area are treated by mechanical and partly biological processes. In 1972, about 120 000 m^3/day of effluent were treated. Wuppertal is chiefly drained by separate sewerage system, only a few areas are drained by combined sewerage system. The amount of waste water and its composition is mainly determined by the industrial plants most of which belong to the chemical industry, metalworking industry, the textile industry and - a smaller number - to the food processing industry. Figure 1 depicts the situation by showing the location of existing and proposed primary treatment plants for industrial waste in Wuppertal. For the time being, the drainage area of the Wuppertal-Buchenhofen sewage works has 24 primary treatment plants, including the treatment of the sludge produced by this process, and 18 plants for waste water treatment without sludge treatment; another 14 plants are still to be constructed. This means, that within the drainage area of the Wuppertal-Buchenhofen sewage works, industrial waste from a total of 56 sources is received which cannot be conveyed via the municipal sewerage system to the sewage works without any primary treatment, such as neutralisation and detoxification. In addition, there are further sources of industrial effluent which, however, may be discharged without any previous treatment. Within the above period, the daily pollution load of the biological treatment plant was about 45 t BOD_5. About 18 t BOD_5/day originated from the Elberfeld plant of Farbenfabriken Bayer AG who produce above all pharmaceuticals and pesticides. Approximately 13 t BOD_5/day were due to other industrial waste, while about 14 t/day were of domestic origin. The domestic waste and the effluent from the other industries is discharged into a municipal sewer and introduced into the biological treatment plant after having passed screen, grit chamber and primary

settling tank. The industrial effluent from Farbenfabriken Bayer is conveyed to the sewage works via a separate sewer (see Figure 2) of a total of about 2 km length, running from the factory site to the sewage works where it is introduced directly into the activated sludge tanks without any preliminary clarification (Figure 3).

The average influent concentration of the municipal sewage, i.e. of the domestic sewage plus the other industrial effluents discharged into the activated sludge plant was 250 mg BOD_5/l, that of the waste discharged by Farbenfabriken Bayer about 2100 mg BOD_5/l, so that the concentration of the mixed waste entering the activated sludge plant was about 420 mg BOD_5/l in 1972. The corresponding COD values were about 400 mg/l for the municipal sewage and 3330 mg/l for the industrial waste, thus the mixed waste showed a COD of 570 mg/l.

Owing to the high proportion of industrial waste and the effluents from Farbenfabriken Bayer, biological treatment involves problems of odour control because of strongly smelling, easily volatile substances contained in the industrial waste or released as intermediate products during the aeration process. Previous tests on a semi-technical scale carried out in 1965/66 had shown that the municipal sewage mixed with the industrial waste from Farbenfabriken Bayer can be purified by the biological method. These tests had shown that with the two-stage process, an aeration period of about 12 hours is required to achieve an effluent concentration of less than 25 mg/l BOD_5 (Figure 4). According to an opinion, this value should not be exceeded by any municipal and industrial wastes discharged into the Wupper. The relatively long aeration periods which were only sufficient when the 2-stage process was applied (i.e. a process comprising a first stage of aeration, intermediate clarification, a second stage of aeration and final clarification) and the problems of odour control made it advisable to test a different process which has been developed in the United States to technical practicability in the last few years.

This process (Unox process, Union Carbide) using pure oxygen was to be tested because it was known from publications on tests carried out in the United States [1] that increased biological degradation was achieved with relatively short aeration periods and that considerably smaller amounts of waste gas are produced in the oxygen aeration process than in the conventional aeration process, so that the odour may be eliminated. Since this process, according to the investigations carried out in the United States, was said to have other advantages in addition, the tests carried out by the Wupperverband were also interesting for other authorities in the Federal Republic. Subsequently the Federal Ministry of the Interior was willing to sponsor the research project of the Wupperverband.

Parallel to the tests carried out by the Wupperverband, similar tests on the same scale were conducted at the Elberfeld plant of Farbenfabriken Bayer with the waste of this plant in order to find out whether the oxygen aeration process will make the separate treatment of the industrial waste more efficient than the treatment of mixed waste. These tests will be reported on separately.

2. Principles of the aeration of waste water, using oxygen

It is assumed to be known that the use of pure oxygen instead of air in the activated sludge process has been tested again and again for many years [2]. McKinney [3], for example, found in 1965 that the use of pure oxygen can be expected to be of advantage with a view to biology as well as research technique. Hitherto, however, the lacking efficiency of the process posed a major problem, since the oxygen was not utilized adequately. According to the existing estimates, the costs of this technique are only then lower than those of the conventional aeration process if about 90 per cent of the total oxygen supplied are utilized. According to the reports available so far, Union Carbide, by developing the

Unox System, has succeeded in developing a process in line with these requirements.

In the activated sludge process, the objective of aeration is on the one hand, to dissolve the oxygen for the supply of the bacteria contained in the waste water and on the other hand, to achieve thorough mixing of the waste water and the activated sludge. According to Henry's Law, the solubility of gas in water is dependent on the pressure of this gas and directly proportional to it. Since the partial pressure of oxygen is only 160 mm Hg in the air, but 760 mm Hg in pure oxygen, a 4.8-fold increase in oxygen concentration at the site of application is possible. Consequently, the oxygen aeration process requires much smaller amounts of gas than the conventional aeration process; the amount of oxygen input required is only about 2 per cent that of the corresponding amount of air. The application of such small amounts of gas, however, does not guarantee adequate turbulence in the activated sludge tank; therefore, additional energy must be supplied for mixing the wastes thoroughly, for example by means of a stirring device.

Owing to the higher oxygen content (8 - 10 mg/l) in the aeration tank, the oxygen supply of the sludge flocs is no longer the limiting factor. The tests carried out so far showed that, when oxygen is employed, higher activated sludge concentrations in the aeration tank may be achieved. This means that, with equal volume of the tank, the sludge load will decrease, and thus more favourable conditions of decomposition will be created, or that, with equal sludge load, the volume of the tank may be reduced. Moreover, considerably smaller amounts of waste gas are produced than in the conventional aeration process. This may be of advantage in certain cases. Only 20 per cent of the gas supplied to the plant are discharged from the plant as waste gas, i.e. less than 1 per cent of the volumes discharged during the conventional aeration process. The oxygen content of the waste gas is about 50 per cent. Considering the volumes, this means a degree of utilization of about 90 per cent.

For the time being, no data can be given on the efficiency of the process under the conditions prevailing in Germany. A project is being prepared on the basis of the test results which will be used for cost estimates. Thus, in the following, I am only referring to the test results obtained with the specific waste of Wuppertal.

3. Objective of the tests, description of the test plant and test programme

It is the objective of these tests to find an answer to the following questions:

1. Which concentration of solid substances should be maintained in the activated sludge tank when oxygen is used, and what is the optimum sludge load?
2. Which detention periods and loads per volume should be maintained in order to achieve an effluent concentration of less than 25 mg/l BOD_5?
3. Which changes in the characteristics of the activated sludge, e.g. the settling characteristics and the sludge index, as compared with the conventional aeration system, are observed, and how much sludge is produced?
4. What is the oxygen demand for complete biological purification to yield an effluent concentration of less than 25 mg/l BOD_5?
5. What are the requirements for achieving an odourless sewage plant effluent, and is treatment of the waste gas required in view of the odour producing substances?
6. Using pure oxygen, which purification efficiency and effluent-BOD_5-concentration may be achieved by altering the existing aeration tanks of the sewage works at Wuppertal-Buchenhofen (detention

period: about 3 hours)?

The test programme was drawn up according to these objectives, the periods of aeration ranging from 3 to 7 hours (Figure 5). At first, the inflow was kept constant over a period of 24 hours, the concentrations varying according to the corresponding discharges. Subsequently, the influence of the quantitative variations of the inflow was studied, using the daily inflow curve. The studies are being terminated by tests for the purification of municipal waste alone, i.e. without industrial waste from Farbenfabriken Bayer using an aeration period of 2 hours. For the time being, this test is not yet finished. The first tests were run after the establishment and start-up of the test plant by the middle of March 1972. After the ripening period and the establishment of some fundamental test conditions, the evaluation of the tests was initiated by the middle of May. This programme is proposed to be terminated by the end of January 1973.

The flow sheet (Figure 6) shows that the plant consists of 3 successive, covered activated sludge tanks, each with a capacity of 0.27 m^3. Two secondary settling tanks with round scrapers were available. The smaller one with a capacity of 0.44 m^3 was used when the period of detention in the activated sludge tank exceeded 4.5 hours, the larger one with a capacity of 1.06 m^3 when the period of detention in the activated sludge tank was shorter than 4 hours. The oxygen is supplied in liquid form, the liquid oxygen being stored in a container outside the pilot plant (Figure 7). The oxygen supply to the activated sludge tanks is controlled by measuring the oxygen content in the first activated sludge tank. The plant as illustrated by Figure 8 is equipped with automatic sampling devices, each of which allows continuous sampling over a period of 3 hours. BOD_5 and COD are each determined on one mixed daytime sample and on one mixed night-time sample, each of which consists of a mixture of 4 three-hour samples. For the determination of the solids content of the activated sludge and of the return sludge, individual samples are taken every 4 hours and combined to give a one-day mixed sample.

In addition, the plant is equipped with devices performing the continuous measurements and individual measurements as shown in Figure 9.

In the influent and in the effluent, COD, solids content and loss on ignition are determined in addition to BOD_5. In several phases of the tests, the effluent and the influent were analysed for organic carbon. Usually, the phosphate content and the content of nitrogen compounds of influent and effluent was tested once a week on 24-hour test samples. At the time the mixed waste was analysed, the plant was fed with about 89 per cent of municipal waste and 11 per cent of industrial waste from Farbenfabriken Bayer. Calculated on BOD_5, one third of the total waste is of domestic origin and about 2 thirds are of industrial origin, about 50 per cent of this amount originating from Farbenfabriken Bayer.

The test plant is operated by 2 sewage works operators. The staff of the first shift stays in the plant from 7 a.m. to 3.45 p.m., the day shift operator checks the plant and takes a sample at 8 p.m. The operation is checked once more at 12 p.m. by the night shift operator of the sewage works. For carrying out the analyses, one laboratory assistant is employed on a full-time basis and another laboratory assistant on a part-time basis. The tests are supervised by a graduated engineer. The analyses were made in the laboratory of the Wupperverband. We are indebted to the laboratory of the Ruhrverband, Essen, who took charge of the determination of carbon content (total carbon and organic carbon). The entire pilot plant, including the measuring and controlling devices, were made available by Union Carbide, Germany.

4. Test results

The following test results refer exclusively to tests on mixed waste, i.e. the municipal waste mixed with the waste from Farbenfabriken Bayer at constant inflow rates. The tests with inflow rates varying corresponding to the curve illustrating the daily inflow to the sewage works have been ter-

minated, but not yet been evaluated. The tests for the purification of the merely municipal waste without the wastes from Farbenfabriken Bayer are being carried out, so that no relevant data can be given as yet. Figure 10 shows the results of test phases II A to VI. The detention periods in the activated sludge tank varied between 3 hours (test phase VI) and 6.7 hours (test phase III). With the exception of test phase II A, the solids content in the activated sludge tanks always exceeded 5000 mg/l, while in phases II B and IV which may be considered as the test phases coming up to the requirements with regard to purification capacity, the solids content always exceeded 6500 mg/l. In all tests, the sludge index was lower than 100 cm^3/g, and even significantly lower than 70 cm^3/g, except for test II A. It should, however, be pointed out, that for the determination of the volume of settled solids in the 1000 ml measuring cylinder according to the american standards, a slowly revolving stirrer was used, since in the narrow cylinder the activated sludge showed a tendency of arching. We believe this procedure to be realistic, since a corresponding thickening was achieved in the final settling tank as may be seen from the data on the concentration of the return sludge. As a comparison, the sludge index in the large-scale plant of the Wuppertal-Buchenhofen sewage works where the conventional aeration process is applied, was 200 cm^3/g on an annual average in 1972. This shows that the activated sludge produced in the oxygen aeration plant has considerably improved settlement characteristics.

In all tests, the production of CO_2 during the decomposition process and the repeated introduction of the resulting mixed gas into the individual reactors involved a distinct decrease in the pH value from more than 7.7 down to 6.1 to 6.3 . Moreover, in all test phases, an oxygen content of more than 10 mg/l was maintained in the reactors. The mean influent BOD_5 measured in the individual test phases was in general considerably higher than 400 mg/l, on some days peak values of up to more than 800 mg BOD_5/l were measured. Usually, COD

was twice as high as BOD_5. The BOD_5 load per volume varied between 1.1 and about 3.1 kg $BOD_5/m^3/day$, depending on detention period and influent concentration. Owing to the high sludge concentration, the sludge load was relatively low, in the most favourable ranges at about 0.2 kg BOD_5/kg dried matter/day, while the heaviest sludge load was about 0.6 kg BOD_5/kg dried matter/day. The amounts of excess sludge produced are also interesting. The figures given include the solids determined in the effluent. These data are ranging from about 0.55 to about 0.3 kg/dried matter/kg BOD_5-decomposition. The measured oxygen consumption, varying between about 1.0 and 1.7 kg O_2/kg BOD_5-decomposition, is also plotted. The individual values will be explained in detail in the following, using further graphs.

Figure 11 shows the effluent concentration related to the detention period of the above test phases. This figure shows clearly that the effluent BOD_5 is dependent on the detention period: an effluent concentration of about 50 mg/l was determined after a detention period of 5 hours, while an effluent concentration of less than 20 mg/l was found after a detention period of 7 hours. Only test II A appears to be an exception. It should, however, be pointed out that in this test only a relatively low sludge concentration could be maintained in the activated sludge tank (about 4600 mg/l), because at that time only the large final settling tank was available where a higher concentration of the return sludge and thus of solids content in the aeration tank could not be achieved with relatively short detention periods of the activated sludge in the final settling tank. I should like to point out once more that this correlation refers to the waste water treated at Buchenhofen, i.e. the mixed waste consisting of municipal waste and waste from Farbenfabriken Bayer. Figure 12 shows the correlation between the effluent characteristics, expressed in mg/l BOD_5, and the sludge load. It is assumed to be known that the sludge load is considered to be the decisive factor with regard to the possible purification capacity in the activated sludge process. In order to

obtain effluent concentrations of less than 25 mg/l BOD_5 for the mixed waters tested, a sludge load of less than 0.3 kg BOD_5/kg dried matter/day must be maintained. In this case, too, test phase II A does not come within the scope of the plotted curve for the above reasons. In the literature [4], values of 0.5 kg BOD_5/kg dried matter/day are given for domestic water. The values obtained here reflect the more difficult decomposition of the mixed wastes used in these tests. Comparison with a conventional aeration plant would be interesting. Unfortunately it was not possible to run another semi-technical plant for carrying out parallel tests. Only for the last few tests, parallel operation was possible. The results of these tests, however, have not yet been evaluated.

As a further correlation function, Figure 13 shows the effluent BOD_5 related to the BOD_5 load per volume. It clearly demonstrates a correlation as may be seen from the plotted means and the curve. Only test II A does not come within the scope of this curve. If an effluent concentration of less than 25 mg/l BOD_5 is aimed at, a BOD_5 load per volume of 1.7 - 1.8 kg BOD_5/m^3/day should be maintained. This fact is within the range given in the "Lehr- und Handbuch der Abwassertechnik" [4] for primarily domestic waste. If the same results can be achieved with the primarily industrial waste treated at Wuppertal-Buchenhofen, this would appear to confirm the advantage of the oxygen aeration process over the conventional aeration process. Unfortunately, however, direct comparisons with a conventional aeration plant are not available in this case, either. The only data which may be compared with the 3 figures are results obtained in the large-scale plant of Buchenhofen, where, however, only partial purification is achieved, and with investigations made in 1965/66 in a two-stage pilot plant, using air. In the large-scale plant, an effluent concentration of 223 mg/l BOD_5 was reached in 1972. The average load of volume was 3.8 kg BOD_5/m^3/day, the influent load was approximately constant. According to Figure 13, the oxygen aeration process

would yield an effluent concentration of 60 - 70 mg/l BOD_5 with the same load. Within the same period, the sludge load in the large-scale plant was 1.2 kg BOD_5/kg dried matter/day on an annual average. If we insert this value into the curve illustrating the correlation between sludge load and effluent BOD_5 in the oxygen aeration process (Figure 12), it would be likely to obtain an effluent concentration of less than 80 mg/l BOD_5. If detention periods are also considered, the annual average achieved in the large-scale plant in 1972 was about 2.8 hours for the above effluent BOD_5 of 223 mg/l. According to Figure 11, an effluent concentration of about 60 mg/l BOD_5 could be achieved in the oxygen aeration process after the same detention period. Even if it is taken into account that the large-scale plant is not run optimally, these comparisons show considerable advantages of the oxygen aeration process over the conventional aeration process.

Considering comparisons with the results obtained in 1965/66 in the semi-technical test plant, using air, and assuming that the degradability of the mixed water has not changed to any significant degree, a two-stage process was required for obtaining an effluent of less than 25 mg/l BOD_5. A total BOD_5 load of 0.7 kg BOD_5/m^3/day, a sludge load of 0.16 kg BOD_5/kg dried matter/day and a detention period of a total of 12 hours had to be maintained. These values are also considerably less favourable than those obtained with oxygen.

The analysis of phosphate and nitrogen compounds contained in the influent and effluent showed that even under optimum conditions, i.e. with a sludge load of about 0.2 kg BOD_5/kg dried matter/day, no oxidation of nitrogen was perceptible. Obviously the composition of the treated waste water is too unfavourable in this respect. Analyses of the waste gas discharged from the oxygen aeration plant for some odour producing substances contained in waste water were carried out but have not yet been evaluated. It can, however, be established that the effluent from the test plant did not evolve the otherwise typical strong odour characteristic of the

mixed water. Parallel tests in two other test plants on laboratory scale were very impressive in this respect. In the effluent from the oxygen aeration plant, no odour was perceptible either, while the conventional aeration plant evolved a very distinct odour typical for the waste water treated in the Buchenhofen sewage works.

Subsequently I should like to show two graphs illustrating the volume of the resulting excess sludge and oxygen consumption. Figure 14 shows the volume of excess sludge related to the effluent concentration, one curve showing the mean from the results of the individual test phases as obtained in the oxygen aeration process and the other showing the correlation in the conventional aeration process in correspondence with the data of the "Lehr- und Handbuch der Abwassertechnik" [4]. It should, however, be pointed out that the data given in the "Lehr- und Handbuch der Abwassertechnik" refer to primarily domestic waste. In the oxygen aeration process, the excess sludge produced related to the BOD_5-decomposition ranges between about 0.3 kg dried matter/kg BOD_5-decomposition with an effluent of less than 20 mg/l BOD_5 and about 0.55 kg dried matter/kg BOD_5-decomposition with an effluent of about 50 mg/l BOD_5. These values also include the effluent solids. The graph shows a considerably lower amount of specific excess sludge produced as against the data given in the literature for the conventional aeration process.

Figure 15 shows the correlation between oxygen consumption in kg O_2/m^3/day and effluent concentration. The results obtained in the tests conducted at Buchenhofen are compared with data from the "Lehr- und Handbuch der Abwassertechnik" [4]. It can be clearly seen from this graph that the oxygen consumption is higher in the oxygen aeration process than in the conventional aeration process. This may furnish an explanation for improved decomposition in the oxygen aeration process. For these two graphs, corresponding values obtained be a parallel test carried out in a conventional aeration plant are not available either. These values, however, may

- at least for two further test phases - be ascertained and may perhaps yield a more genuine comparison than the one given here.

The results described in this paper should be regarded as preliminary results, since the tests have not yet been finished and the evaluation is not yet complete. In particular, the evaluation does not include reference to the impact of peak loads, such as those which occurred when the pump for the transport of the municipal waste failed for a short period and the plant was fed with merely industrial waste for several hours. The influence of sudden heavy discharges of oil which during the test period occurred several times, has not yet been finally evaluated. Data on the economy of the process are not available as yet. As mentioned at the beginning, a large-scale plant is being dimensioned on the basis of the test results, and a project is being prepared, including data on the costs. Only when these data will have been submitted, data on the efficiency of the plant can be given.

5. Summary

The tests were aimed at finding answers to the questions listed under Section 3. These questions can be answered as follows:

1. With optimum dimensioning of the final treatment a sludge concentration in the activated sludge tanks of at least 5 g/l - but usually of more than 6 g/l - could safely be maintained in the oxygen aeration process. This value is significantly higher than all concentrations obtained with the waste of Buchenhofen over a prolonged period and also higher than the values given in the literature with regard to conventional aeration plants.

2. In order to obtain an effluent concentration of less than 25 mg/l BOD_5 on the basis of the mixed waste treated at Buchenhofen, using the oxygen aeration process in a one-stage operation, a detention period of 6 hours is sufficient. In this case, the BOD_5 load per volume should be about 1.7 - 1.8 kg BOD_5/kg/day, and the sludge load should not exceed 0.3 kg BOD_5/kg dried matter/day.

3. In all tests, the sludge index was significantly lower than 100 cm^3/g and thus considerably more favourable than in Buchenhofen large-scale plant with an annual average (1972) of about 200 cm^3/g. In the final settling tank, the activated sludge thickened readily. With the exception of one test phase, means ranging from 16 to 25 g/l were determined. The amount of excess sludge produced, 0.3 - 0.55 kg dried matter/kg BOD_5 decomposition, depending on effluent quality including the effluent solids, was considerably lower than the values given in the literature.

4. In the individual phases of the test, the oxygen consumption was about 1.0 - 1.7 kg O_2/kg BOD_5-decomposition. As compared with the conventional aeration process, at least in the case of primarily domestic waste, the oxygen consumption appears to be higher than in the conventional aeration process. But in addition to sludge load, the quality of the waste, expressed by the ratio of BOD_5 to COD, also appears to affect the oxygen consumption. According to the results of the evaluations made so far, a value of 1.2 kg O_2/kg BOD_5-decomposition should be used for the estimate.

5. According to the available test results, the plants did, neither in the waste gas nor in the sewage plant effluent, evolve the odour characteristic of

conventional aeration plants, so that additional treatment of the waste gas does not appear to be required.

6. According to the results obtained hitherto, it would appear to be possible for the mixed waste treated at Buchenhofen to use tanks of half the size of those used in the conventional aeration process. But among other things, the construction of the tanks will be more expensive because of the cover, so that a corresponding 50 per cent drop in the investment cost is not to be expected. No data can be given as yet with regard to the economy of the process. A corresponding plant is being projected. Subsequently tenders with regard to construction and mechanical equipment can be invited, and the operating costs and total annual costs can be ascertained, the operating costs certainly being a major factor of total process costs.

7. Concluding we should like to emphasize once more that for the time being all data and conclusions only apply to the municipal waste of Wuppertal combined with the industrial waste from the Elberfeld plant of Farbenfabriken Bayer used in the test. It should be checked by tests carried out in other places to what extent the results obtained here may be generalized and applied to other cases of practical interest.

Literature

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Fig.1 Number and site of industrial waste water pretreatment plants in Wuppertal

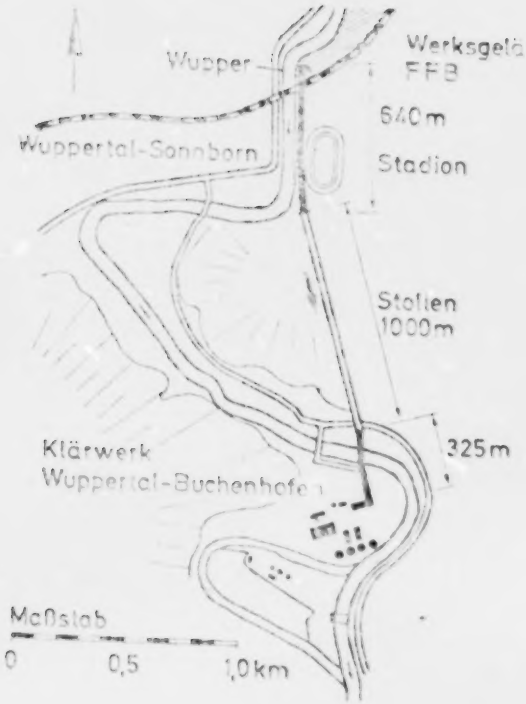

Fig.2 Waste water treatment plant at Wuppertal-Buchenhofen and waste water canal from the Bayer AG

Fig.3 Lay-out of the waste water treatment plant at Wuppertal-Buchenhofen

Abwasser		Werksabwasser		Städtisches - Abwasser mit Werksabwasser 4 : 1		
Betriebsweise		einstufig	zweistufig	einstufig	zweistufig	
Belüftungszeit	h	6	12	12	6	12
BSB_5 – Zulauf	mg/l	1700	1700	300	385	348
BSB_5 – Ablauf	mg/l	112	57	35	41	20
Abbau	%	94	97	88	89	94
CSB – Zulauf	mg/l	2540	2540	617	762	616
CSB – Ablauf	mg/l	405	305	231	271	177
Abbau	%	84	88	63	64	71

Fig.4 Test results of mixed liquor purification with conventional two stage aeration

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Versuchsreihe	Datum	Aufenthaltszeit	Versuchsbedingungen
IIA	11.5.-7.7.1972	6h	konstante Zulaufmenge, natürl. Konzentrationsschwankungen
IIB	8.7.-6.8.1972	6h	wie IIA
III	7.8.-30.8.1972	7h	wie IIA
IV	31.8.-2.10.1972	6h	wie IIA
V	3.10.-23.10.1972	4,4h	wie IIA
VI	26.10.-12.11.1972	3h	wie IIA
VII	13.11.-20.12.1972	5,5/7,5h	Zulaufschwankungen gemäß Tageszuflußkurve
VIII	2.1.-26.1.1973	7h	wie IIA, jedoch o. Abwasser

Fig.5 Testprogramme for mixed liquor treatment by oxygen

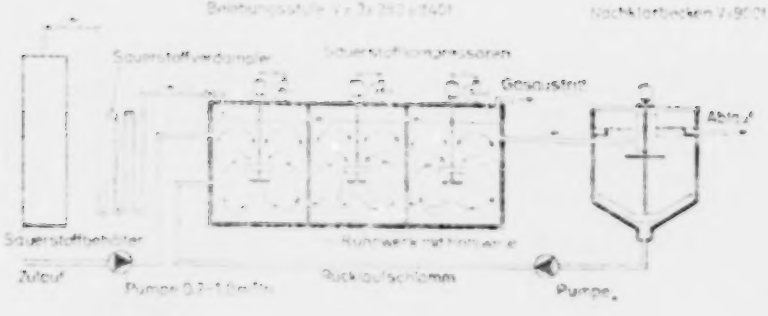

Fig.6 Scheme of the pilot plant at Wuppertal-Buchenhofen

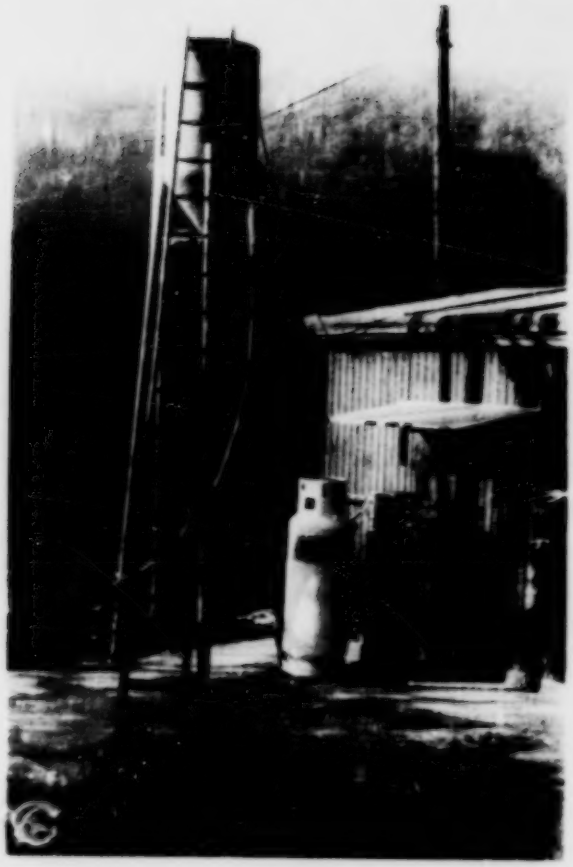

Fig.7 The liquid oxygen storage of the pilot plant

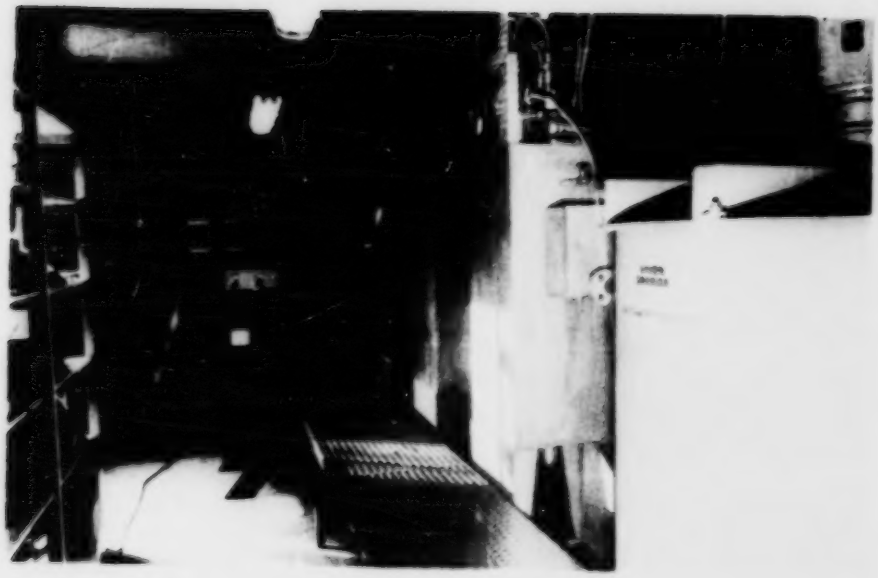

Fig.8 Equipment of the pilot plant at Wuppertal-Buchenhofen

Kontinuierliche Messungen	Einzelmessungen	Häufigkeit
Gasmenge im Zulauf (O_2)	Temperatur in den BB	2x täglich
Gasmenge im Ablauf	Zulaufmenge	2x täglich
O_2 - Gehalt im BB	Rücklaufschlammenge	2x täglich
O_2 - Gehalt im Abgas	Absetzvolumen (30')	1x täglich
pH - Werte im BB	Gastemperatur im Zulauf	je 6 x täglich
	Gastemperatur im Ablauf	je 6 x täglich
	Gastemperatur im Rücklauf	je 6 x täglich
	O_2 - Gehalt in der Gasphase über den BB	6x täglich

Fig.9 Measurement programme of the pilot plant

Versuchsphase		I A	I B	II	III	V	VI
Versuchszeit		5 - 7	7 - 8	8 - 10	9 - 10	11 - 12	12 - 13
Aufenthaltszeit im BB	h	5,9	6,0	6,7	5,9	4,4	3,0
Feststoffgehalt im BB	mg/l	4 634	6 515	5 313	6665	5965	5284
Schlammindex	ml/g	62	66	62	55	52	54
Feststoffgehalt im Rücklauf	mg/l	13 216	15 484	12 953	25 000	21 642	17 838
pH - Wert im Zulauf		8,1	8,0	7,8	7,8	7,7	7,7
pH - Wert im BB		8,2	8,1	8,2	8,1	8,3	8,2
O_2 - Gehalt im BB	mg/l	13,8	11,2	14,1	15,6	17,1	15,2
BSB$_5$ im Zulauf	mg/l	422	361	312	594	434	406
BSB$_5$ im Ablauf	mg/l	48	23	17	25	34	45
BSB$_5$ Abbau	%	89	94	95	96	93	89
CSB im Zulauf	mg/l	872	720	772	970	860	1100
CSB im Ablauf	mg/l	192	168	141	183	224	264
CSB Abbau	%	78	77	77	81	73	76
BSB$_5$-Raumbelastung	kg BSB$_5$/m³ d	1,74	1,46	1,10	2,39	2,64	3,53
Schlammbelastung	kg BSB$_5$/kg TS d	0,36	0,22	0,21	0,34	0,45	0,66
spezifische Abgasmenge	kg BSB$_5$ Abbau	0,45	0,32	0,24	0,36	0,43	0,54
O_2 - Verbrauch	kg O_2/kg BSB$_5$ Abbau	1,22	1,19	1,20	1,22	0,97	1,19

Fig.10 Test results of the waste water treatment by oxygen

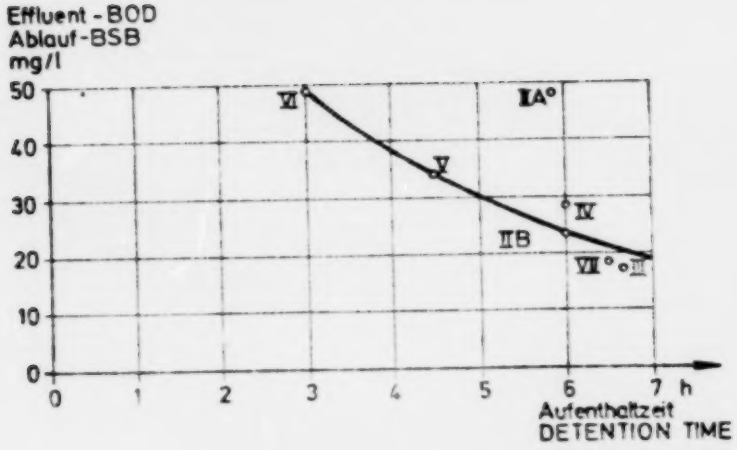

Fig.11 BOD effluent concentration in relation to detention time

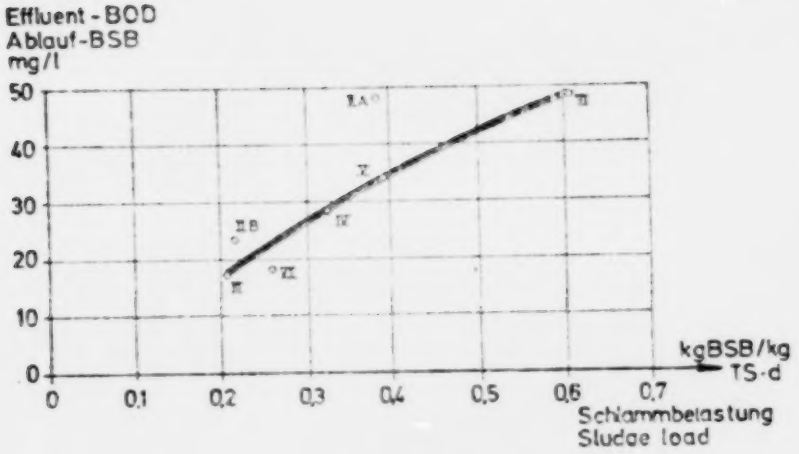

Fig.12 Effluent BOD in relation to sludge load

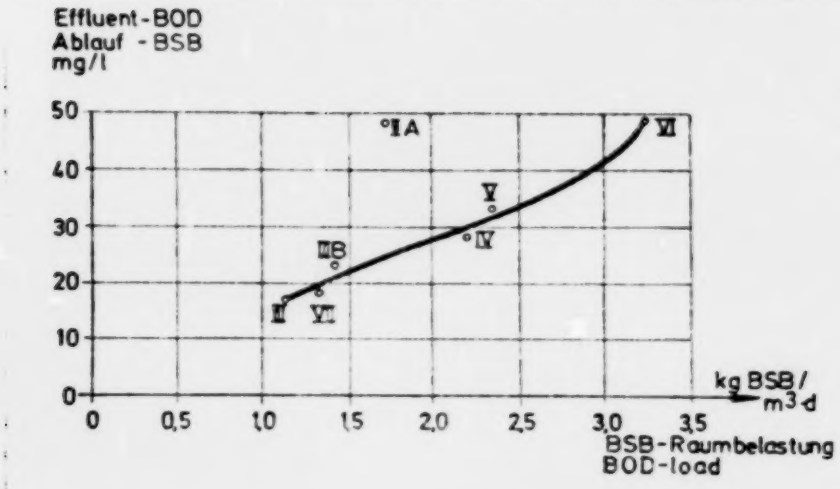

Fig.13 Effluent BOD in relation to BOD load

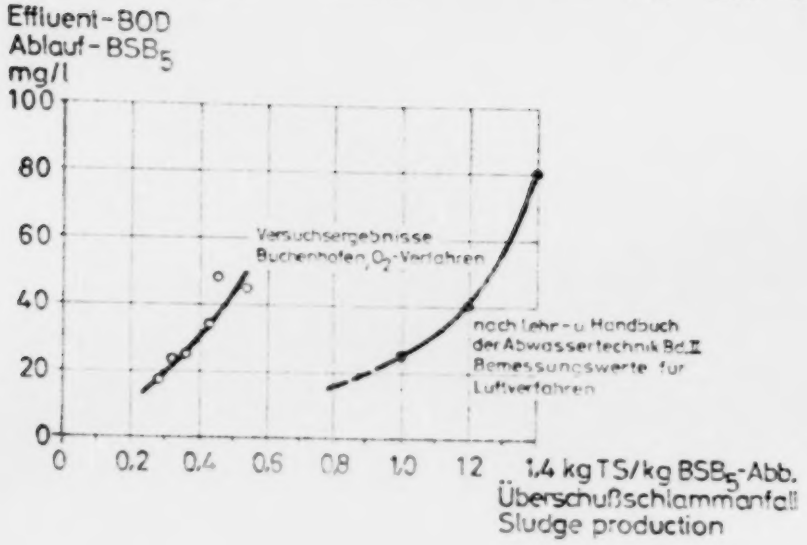

Fig.14 Effluent BOD in relation to sludge production; results of the oxygenation in comparison with conventional aeration

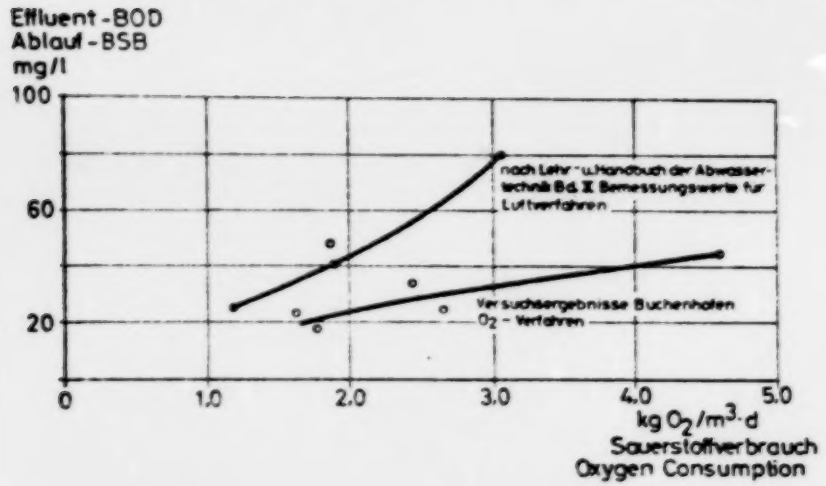

Fig. 15 Effluent BOD in relation to oxygen consumption

BIOLOGICAL PURIFICATION OF WASTE WATER, USING OXYGEN

by
Dr. K. Mack
Wuppertal

One of the factors decisive for the effectiveness of a biological treatment plant using the activated sludge process is the adequate supply of the aerobic microorganisms with oxygen. We all know the undesirable effects of anaerobic conditions in the activated sludge tanks. The oxygen supply is a limiting factor for BOD load as well as for the concentration of the activated sludge. Thus the removal efficiency of conventional sewage plants can usually only be improved by increasing the volume of the tanks. With increasing amounts of waste and rising biological load, this requires the extension of the sewage plant areas. Considering the available sites, this will be hard to realize. In addition, the proportion of the nitrogen introduced into the waste together with the air, that escapes without being utilized is a further disadvantage of the conventional aeration plants because it produces undesirable stripping effects which are responsible for the characteristic odour evolved from clarification plants.

As a consequence, it would appear to be reasonable to use oxygen enriched air or even pur oxygen for the aeration of the biomass. As early as about 20 years ago, Okun carried out laboratory tests where he tried to use oxygen instead of air. At first, these tests did not entail any technological development. Only in the last few years has this process been applied on a technical scale, particularly in the United States. The tests carried out by Union Carbide at Batavia Sewage Works by the end of the sixties, which in the meantime have led to the establishment of several large-scale plants in the United States, are known. In the Federal Republic, Linde has in the meantime started a corresponding test series on a semi-technical scale.

With the biological purification of wastes from the chemical industry, odour emissions may pose a major problem. For this reason, a pilot plant from Union Carbide was established at the Elberfeld plant of Farbenfabriken Bayer AG early in 1972 in order to test the practicability of oxygen aeration,using the Unox process as a model. The flow sheet in Figure 1 shows that.

The test plant consists of two stages. Each stage is equipped with a secondary settling tank. The first stage consists of 4, the second stage of 2 tanks. The capacity of the individual tanks is about 230 l. It can be seen from this set-up that the period of detention in the first stage is twice that of the second stage. The waste is introduced into tank 1 of the first stage and conveyed trough connecting pipes into tanks 2, 3 and 4 and from there into secondary settling tank 1 together with the discharged activated sludge. The clarified waste from the first stage is fed to tank 1 of the second stage via the overflow of secondary settling tank 1 and from there into secondary settling tank 2 via tank 2 of the second stage. Each secondary settling tank has a capacity of about 600 l. The secondary settling tanks are equipped with an automatic rabble arm. In addition, there is the possibility of introducing part of the influent directly into tank 1 of the second stage. The oxygen is supplied via pressure-regulating valve and gas meter to the gas chamber of tank 1 of the first stage. The oxygen is then sucked off from the gas chamber by the compressor of tank 1 and pressed via rotameter into the hollow shaft of the agitator. A diffuser is employed to distribute the gas in the liquor-sludge mixture. The excess gas is conveyed from the gas chamber of tank 1 via connecting pipe into the gas chamber of tank 2. In tank 2 and the following tanks, the same process is repeated. The residual gas escapes into the atmosphere from the gas chamber of tank 4 via a second pressure valve and a second gas meter. The plant is completely closed to the atmosphere, the only opening being the waste exhaust. It is the function of the pressure valves to maintain the pressure in the gas chambers of the individual tanks at a constant level of about 50 mm (water-column). The oxygen supply of the second stage is handled in the same way as that of the first stage. Both, stages 1 and 2, are equipped with a pump for transporting the return sludge and removing the excess sludge. The flow sheet shows the cascade-like design of the series of tanks which is to ensure optimum utilization of the oxygen. With this set-up, the activated sludge

of the first tank must absorb the entire pollution load. With highly polluted wastes, as for example in the present case, load per volumn and sludge load in the first tank increase to a degree that even with the application of pure oxygen, the concentration of dissolved oxygen is inadequate. For this reason, a circulating pump was installed to thoroughly mix the contents of tanks 1 and 2.

The Elberfeld plant of Bayer AG discharges about 12000 m^3/ day of waste from their production plants. BOD load is about 20 tons/day, COD load about 37 tons/day. About 150 different agents for pharmaceuticals and pesticides are produced in this plant. The waste contains a correspondingly large number of different substances.

Figure 2 and 3 show the most important components of the waste and their individual concentrations. The first 4 components, acetone, ethanol, methanol and isopropanol, are responsible for more than 60 per cent of the COD load.

After adjusting the pH to between 8 and 9, the industrial effluent was introduced into the pilot plant without any additional pre-treatment. After an initial operation period of about 6 weeks, the following results were recorded.

The amount of influent was adjusted so as to yield a detention period of about 6 hours in the first aeration stage and of about 3 hours in the second aeration stage (Figure 4). The ratio of return sludge was adjusted to 42 per cent through 49 per cent of the influent in the first stage and to 50 per cent of the influent in the second stage. This return sludge ratio gave a solids concentration ranging from 8200 to 9800 mg/l in the first stage and from 6300 to 7700 mg/l in the second stage. The solids concentration of the return sludge was 22 to about 26 g/l in the first stage and ranging from 18 to 21 g/l in the second stage. Further important characteristics are the sludge index, ranging from 45 to 51 in the first stage and from 50 to 54 in the second stage. The concentration of dissolved oxygen was on an average varying between 11 and 14 mg/l in the first stage, and between 16 and 20 mg/l in the second

stage. A sludge load of between 0.74 and 0.81 was maintained in the first stage and of 0.08 to 0.24 in the second stage. The higher sludge load of 0.24 in the second stage was due to the application of step feeding, i.e. about 10 per cent of the waste were introduced directly into the second stage. The use of this method resulted in a slight improvement of removal efficiency.

With an influent BOD_5 ranging from 1700 to about 1900 mg/l, an effluent BOD_5 of 35 to 40 mg/l was achieved (Figure 5). Influent COD was 3200 to 3500 mg/l. An effluent COD of 377 to 420 mg/l was obtained. With a period of detention in the activated sludge tanks of a total of 9 hours, this corresponds to a BOD_5 removal of 98 per cent and a COD removal of 87 to 88 per cent.

From earlier tests on the biological degradation of the industrial waste, using the conventional process, we know that an aeration period of about 17 hours is required to achieve an effluent BOD_5 of 40 mg/l. It is known that with the conventional aeration process, activated sludge concentrations usually are about 3 g/l, while with the oxygenation aeration process, a biomass of 8 to 10 g/l can still be supplied with oxygen without any difficulty. With the conventional process, the sludge load ranges from 0.3 to 0.6 kg BOD_5/kg biomass/day, while with the oxygenation aeration process, it may be increased to 0.8 through 0.9 kg BOD_5/kg biomass/day. The same holds good for the load per volume which in the oxygenation process may be 2 to 3 times higher than in the conventional aeration process. This allows the use of considerably smaller aeration tanks.

Figure 6 shows the development of BOD_5 in the waste fed to the pilot plant and the development of BOD_5 in the effluent of the first and second stages. It can be seen that the influent BOD is subject to considerable variations which, however, have practically no effect on the effluent BOD of the second stage. It is interesting to note the marked increase in effluent BOD in the first stage and in the influent to the

second stage. This increase was due to defective oxygen supply in the first tank of the first stage. Anaerobic conditions were produced in the entire first stage. Owing to the increased BOD load in the second stage, considerably higher amounts of excess sludge were produced in the second stage, so that the biomass that had turned anaerobic in the first stage could be replaced by the excess sludge of the second stage. Even during the period of defective operation, the effluent BOD_5 of the second stage was lower than 60 mg/l (Figure 7).

Figure 8 shows the frequency distribution of the BOD values in the effluent of the first and second stages. It can be seen from the graph taht 95 per cent of all BOD values in the effluent of the second stage are lower than 50 mg/l, and that 50 per cent of all BOD values in the effluent are lower than 40 mg/l BOD_5.

Figure 9 shows COD plotted against effluent BOD of the second stage. The lower part of the curve shows, that, with a relatively marked decrease in COD, the BOD does not change to any significant degree. On the other hand, the test results allow to forecast that with a decrease in COD to values of less than about 300 mg/l, the costs of the oxygen aeration process will also increase considerably. In our mind it is therefore doubtful whether any further COD or BOD reduction in industrial waste by biological methods as in the present case will be of advantage (Figure 10).

In order to achieve optimum effectiveness of the activated sludge process, the composition of the nutrient substrate is of decisive importance. The ratio of BOD_5/nitrogen/phosphorous, for example, should be about 100:5:1. At times, particularly at times of peak loads due to the discharge of solvents, the industrial waste contained too small amounts of nitrogen and phosphorous. The slide shows the decrease in BOD removal efficiency resulting from an increase in sludge load without any addition of nutrients, and constant BOD removal efficiency even with increased sludge loads when nitrogen and phosphorous are added in the form of ammonia and phosphate.

Figure 11 shows a diagram where the oxygen consumption per kg of removed BOD_5 and per kg of removed COD is plotted against the sludge load. With a sludge load of less than about 0.25, a marked increase in the oxygen consumption per kg of removed BOD is observed. This means that with low sludge loads, the biomass is subject to autolysis and, with adequate oxygen supply, the microorganisms decompose themselves. As mentioned before, the highest oxygen consumption is observed in the first two tanks of the first stage. About 70 per cent of the total BOD removal takes place in these two first tanks. Therefore the sludge load is significantly lower in the subsequent tanks and reaches values of less than 0.25, i.e. part of the aeration stage is used for mineralising the excess sludge. For this reason it is understandable that with the multi-stage oxygenation process as applied in the tests, smaller amounts of excess sludge are produced than in the conventional aeration process under comparable conditions. According to the test results, the amount of excess sludge was in the oxygenation process reduced by about 15 per cent as compared to the conventional aeration process.

BOD load, degree of degradation, amount of excess sludge and thus oxygen demand/kg of BOD_5 removal are parameters with significant bearing on the size of a plant and thus on investment and operating costs. No detailed data on these questions are available as yet because reliable figures can only be obtained from the application of these processes in large-scale plants.

In the tests, the oxygenation process had the following advantages over the conventional aeration process:

1. The pressure of pure oxygen, being 4.8 times that of atmospheric oxygen, involves a correspondingly high oxygen content in the activated sludge tanks, so that the plants can be run with higher sludge concentrations and loads.

2. Pure industrial oxygen can be utilized to 90 per cent. The remaining waste gas contains about 50 per cent of oxygen, thus facilitating the removal of any odour producing sub-

stances by catalytic or thermal oxidation if necessary.

3. Waste water purification using oxygen is carried out in closed systems. Only about 1 per cent of waste gas is produced as compared to the conventional aeration process, so that odour emissions and the distribution of germs due to stripping effects are considerably reduced.

Further advantages of the oxygen aeration process are improved settlement characteristics and a smaller amount of excess sludge, thus reducing the costs of sludge treatment. On the other hand, however, any possible drawbacks should not be overlooked either. Oxygen, being an expensive oxidant, requires the use of closed containers which are considerably more expensive than open tanks. Moreover, safety precautions have to be observed when working with oxygen. This, though not representing any technical problem, will increase costs. The problem of corrosive effects and the choice of suitable materials have not been adequately clarified either. For these reasons, no final word can be said on waste water purification with industrial oxygen as yet. Where, however, not much space is available for the conventional aeration plants or where the removal of odour emissions is to be given priority, the prospects of the oxygen aeration process may certainly be regarded as excellent.

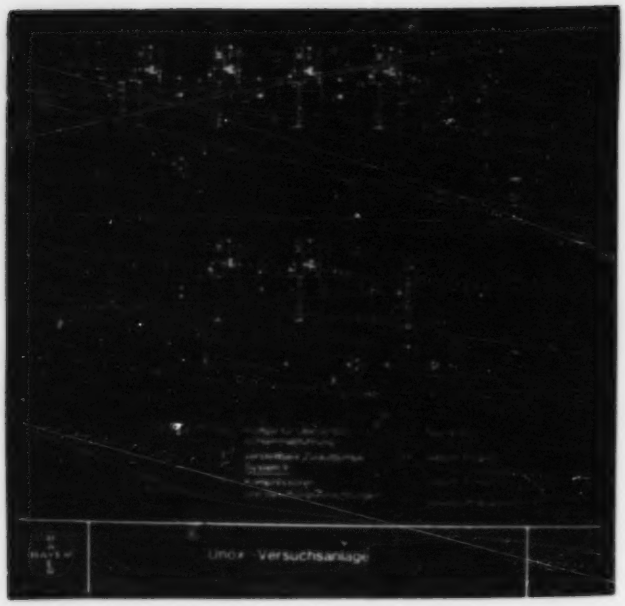

Fig. 1

Typical Wastestream Chromatographic Analysis

Component	Concentration mg/l	Estimated CODmg/l	Estimated TOCmg/l	Actual CODmg/l	Actual TOCmg/l
Acetone	296	833	453		
Methanol	781	820	1171		
Methanol	118	240	244		
Isopropanol	294	453	513		
Chloroform	14	28	29		
Dichloromethane	4	8	8		
Butanon	7	14	14		
Benzol	3	-	-		
Methylenchlorid	9	18	19		
Toluol	12	16	17		
Xylol	6	12	12		
Öl		2230	2230	2000	2000
Antifoam		50	45	100	45
		2946	3176	2100	2045

Fig. 2

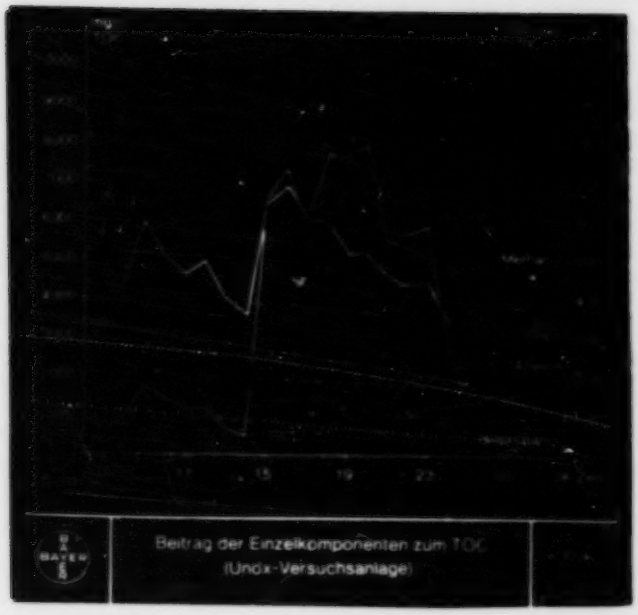
Beitrag der Einzelkomponenten zum TOC
(Unox-Versuchsanlage)

Fig. 3

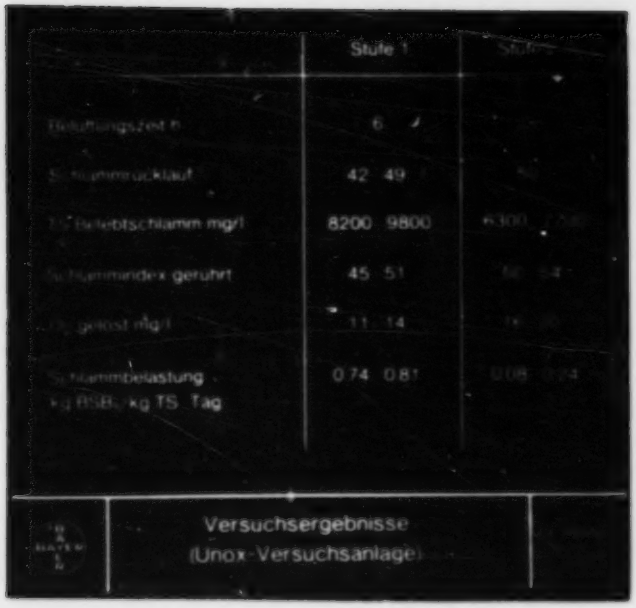
Stufe 1
Belüftungszeit h
6
Schlammrücklauf
42 49
Betriebsschlamm mg/l
8200 9800
Schlammindex gerührt
45 51
gelöst mg/l
11 14
Schlammbelastung
kg BSB kg TS Tag
0.74 0.81
Versuchsergebnisse
(Unox-Versuchsanlage)

Fig. 4

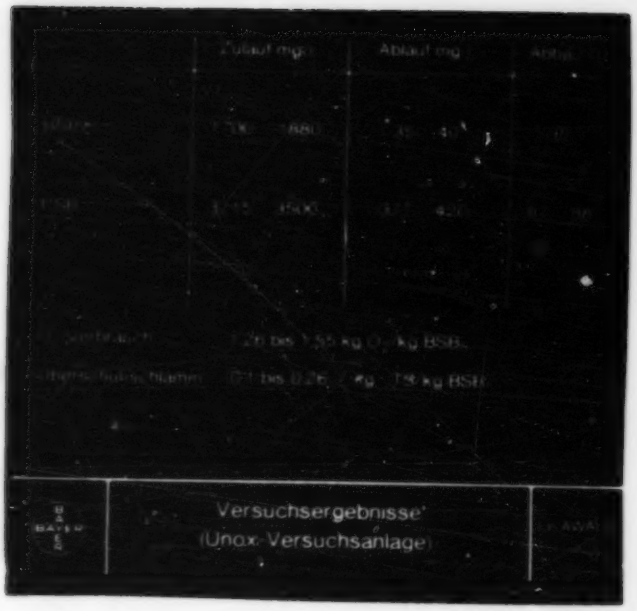

Fig. 5

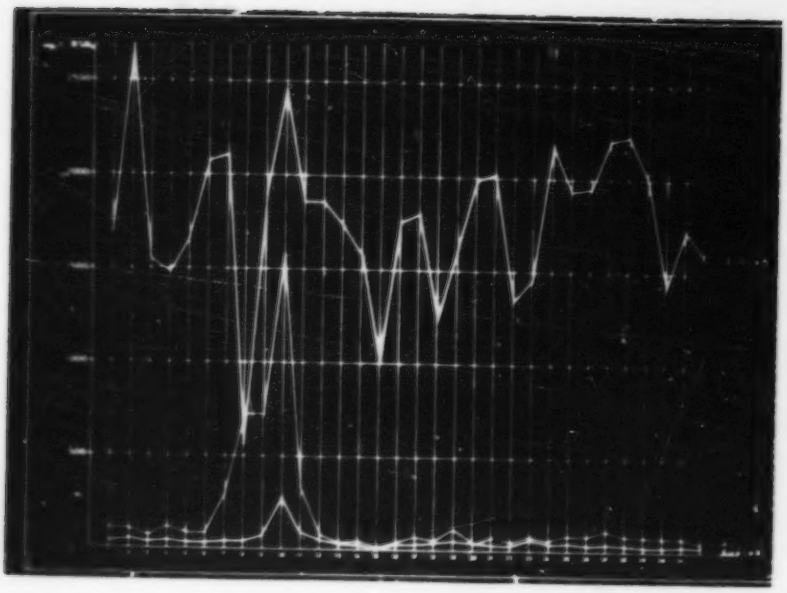

Fig. 6

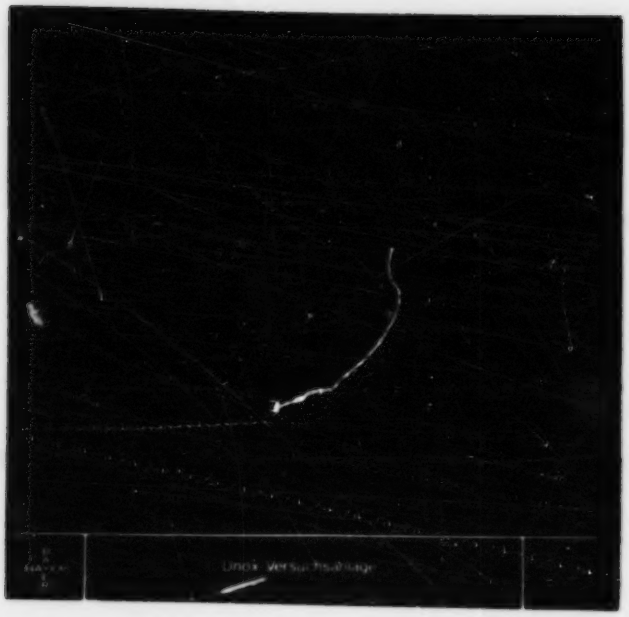

Fig. 7

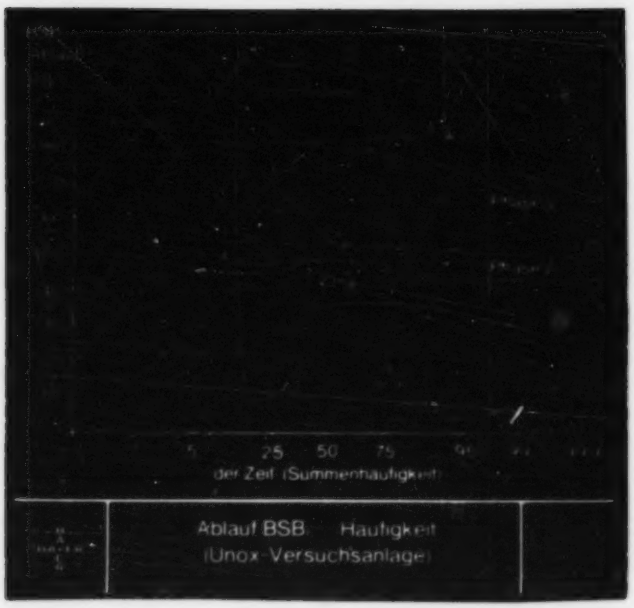
25
50
75
der Zeit (Summenhäufigkeit)
Ablauf BSB Häufigkeit
(Unox-Versuchsanlage)

Fig. 8

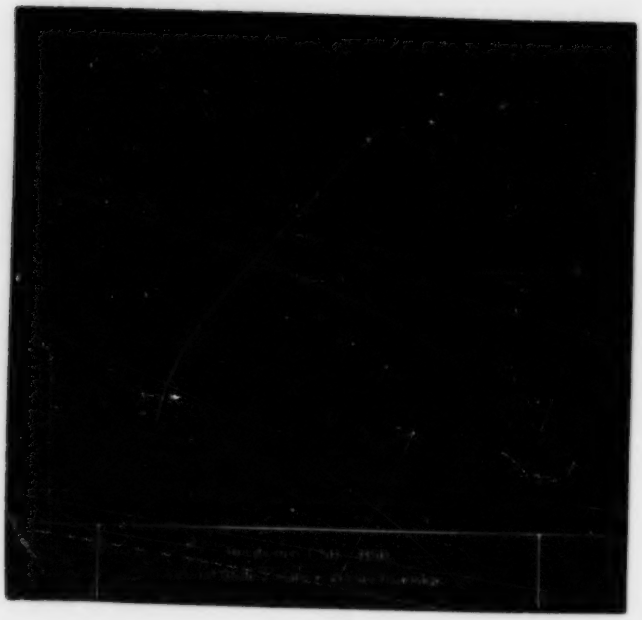

Fig. 9

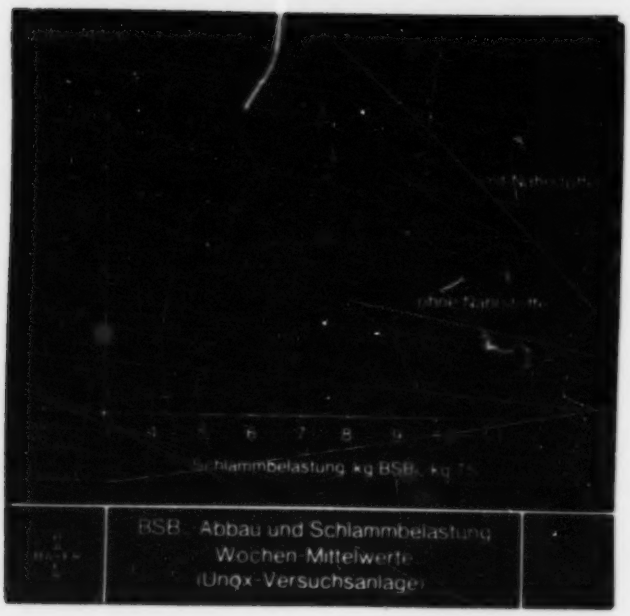
Schlammbelastung
BSB-Abbau und Schlammbelastung
Wochen-Mittelwerte
(Unox-Versuchsanlage)

Fig. 10

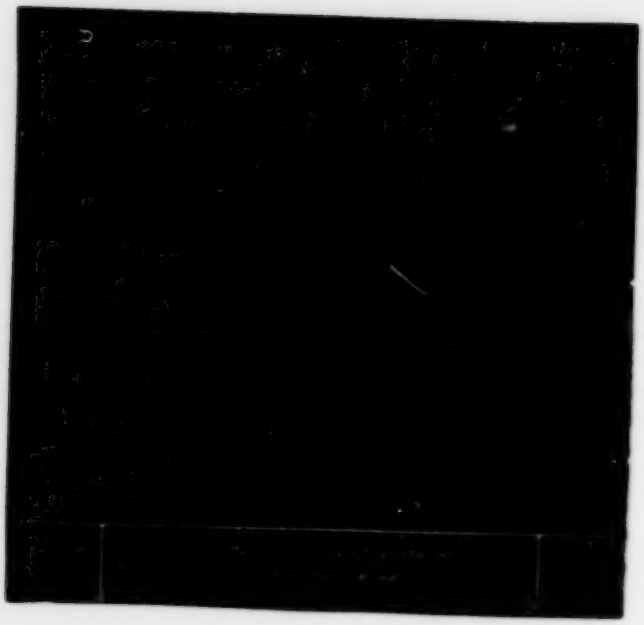

Fig. 11

RESEARCH INTO THE USE OF OXYGEN IN SEWAGE TREATMENT IN THE UNITED KINGDOM

by
A. H. Goodman
London

1. In the United Kingdom it has been usual to expect an effluent discharged to a river to satisfy the conditions of 20 mg/l BOD_5 and 30 mg/l suspended solids content. In order to achieve consistently these conditions it has been the practice of sewage works operators to achieve some measure of nitrification of the ammonia content. This created stable conditions of treatment and the nitrate so produced gave a reserve of oxygen in the river which could be drawn upon when the dissolved oxygen content of the river water reached a certain low level. The amount of effluents now being discharged to our rivers is increasing and this causes a consequent lack of dilution which reduces the ability of the rivers to continue purification after the effluents have been discharged to them. The river authorities responsible for imposing conditions on sewage effluents being discharged to rivers have had to require a better standard of purification than was necessary formerly. It is expected that more and more discharges will have to be treated more fully as time proceeds, and the standards likely to be imposed will include a limit for the ammonia content and this will mean that nitrification of the effluent will have to proceed in order to reduce this ammonia content. Thus, in the United Kingdom nitrification of sewage effluents is of increasing importance, and it is this fact that makes the experiments being carried out using oxygen in waste water treatment in the United Kingdom directed more to achieving nitrification than to simply reducing high levels of organic pollution to some low figure. It is possible, of course, to achieve the necessary levels of nitrification using conventional plants such as trickling filters or activated sludge plants using air, but the works required to produce this high standard of purification become very large and consequently expensive. If it is found possible to achieve the results with a more compact plant using oxygen it could have advantages.

2. Experiments using oxygen enriched air under a cover a surface aeration type of plant was started privately by one large authority some time ago and these experiments have now reached a conclusion. It is expected that a report on this work will be published in about 6 months time. The unit was a surface aeration unit of Ames Crosta and it had a capacity of about 1,500 gallons. It was a conventional aeration unit but a cover was built over it and the atmosphere contained inside the cover was enriched with oxygen. This unit will be moved soon to another authority's works and when it is installed experiments will be conducted under the joint guidance of the company promoting the plant, the local authority concerned and Central Government as part of the CCMS research in the United Kingdom. The plant will be sited at Rotherham.

3. Two other plants are being used in the experiments using oxygen. Both these experiments are being supported partly by Central Government as part of United Kingdom contribution to the research into the use of oxygen in waste water treatment. One of these plants is in process of construction at the Davey Hulme works of Manchester City Rivers Department. This plant will be able to treat between 3,000 and 6,000 gallons per day. At the Davey Hulme sewage treatment works it will be possible to treat firstly a sewage of almost entirely domestic origin, then a mixture of domestic and industrial waste, and it is possible that the third phase will be that the plant will be used to treat a discharge of purely industrial waste which is received at this works through a separate pipeline. This plant is manufactured by Satec and the experiments, from the point of view of that company, are an extention of work carried out by its corporate company in the USA. Satec are assisting in the Central Government's investigation by concentrating their pilot plant work at Manchester, and they will continue to carry out separate laboratory scale work at their laboratories at Crewe. It is not expected that results will be available for publication before the end of 1973.

4. The other pilot plant has been in use since the end of May 1972, and the final results and report will be available in the middle of 1973. This plant is a UNOX pilot plant and it is sited at Ray Hall sewage treatment works of the Upper Tame Main Drainage Department at Birmingham. This plant is in the middle of an intensive test programme to evaluate the use of high purity oxygen for waste water treatment. The aim of the programme is to prove the potential economics and advantages of dissolving oxygen from a relatively pure supply of oxygen gas as typified by the UNOX process, data are being accumulated periodically to assess the performance of the test unit, so at the mid-point of the test programme an evaluation of its progress can be made.

5. The waste water is a municipal sewage with a heavy industrial content. The local industries include many plating industries, organic chemical companies producing sulphur containing compounds for rubber processing, organic solvents and acid pickling liquors from metal treatment plants. The average suspended solids of the primary settled sewage is 280 mg/l and the BOD_5 of the primary settled sewage is about 225 mg/l with occasional peak values reaching 450 mg/l and 385 mg/l respectively. The average COD to BOD ratio is over 3 compared to the normal municipal waste which should average about 2. On occasions some industrial spillages have rendered the sewage received at the Ray Hall sewage works yellow in colour and with a sulphorous odour and on several occasions the pH has dropped to 3.5. The average concentrations of toxic metals is 0.42 mg/l chromium, 0.58 mg/l copper, 0.89 mg/l zinc and 0.31 mg/l lead, some samples have been examined for chlorinated hydrocarbon content and carbon tetrachloride and 1-1-1 trichloroethylene have been identified. It is believed that thiourea can be present in this sewage. The temperature of the incoming sewage ranges from 9 ^{o}C to 17 ^{o}C.

6. The pilot plant used has a reactor volume of 6 cubic metres (1,300 gallons) and is mounted in a self-contained mobile trailer. The reactor unit has four compartments, or stages, to simulate a plug flow reactor. Within the trailer there are all the instruments and equipment necessary for operation. Initially, this plant was operated as a single step nitrification plant, that is, the primary settled sewage and the recycled sludge were fed to the reactor and the mixed liquor was separated in the final settling tank. After the plant had been commissioned and its constants established, it was operated in a steady state from about mid-September onwards.

7. The plant was found to oxidise satisfactorily waste water to give a very low soluble BOD in the final effluent with values from 3 to 15 mg/l. However, the suspended solids content of the effluent was high due to carry over of activated sludge from the final settling tank. This could have due to the small scale of the final settling tank but possibly due also to some of the contamination due to the industrial contribution to the sewage. Nitrification proceeded to a limited extent, with an average concentration of oxidised nitrogen of 5 mg/l. The mixed liquor suspended solids concentration was maintained at between 5,000 mg/l to 9,000 mg/l. At all times this sludge was found to have an excellent settlement characteristic and the returned sludge had a concentration which averaged over 26,000 mg/l.

8. Because the nitrification was occurring to such a small extent the programme for operating the pilot plant was considered by the Steering Committee reviewing the programme. This Steering Committee comprised representatives from the Department of the Environment, the Water Pollution Research Laboratory, the Upper Tame Main Drainage Department and Wimpey-Unox. It was decided to change the method of operation of the pilot plant to encourage nitrification. It was decided therefore to install an intermediate settling tank and to convert the pilot plant to two-step operation. The

two-step system employed a reactor to remove the carbonaceous material from the waste, then after the settlement of that sludge, the effluent passed to the second stage in the second reactor where the retention period was very much greater in order to induce nitrifying bacteria to proliferate. Thus, two separate cultures of organism were being provided, one to remove the BOD and the other to nitrify the ammonia. The reasons for instituting this change were:

i. The toxicity of the waste water necessitated long sludge ages to allow the growth of nitrifying bacteria. It was thought that the short retention period in the single step process of the UNOX plant was insufficient for the nitrifying bacteria to become acclimatised to the conditions and to be able to function. This was aggravated by the rather low temperature of the waste water that is, about 11 ^{o}C and it was thought that the nitrifying organisms would be slow to develop at this temperature.

ii. The high suspended solids content of the waste required a continuous loss of surplus sludge and this made it difficult to obtain sufficiently long sludge age for the nitrifying bacteria to develop.

iii. Industrial spillages occurred frequently enough to interfere with the formation of a stable sludge. It is felt that the buffering capacity of the first step in this two step system would overcome the interference due to these industrial spillages and any other variations in the incoming sewage.

9. The loading of the first stage, that is, the high rate carbonaceous removal stage was up to 0.85 lbs BOD per day per lb of mixed liquor volatile suspended solids. The Water Pollution Research Laboratory has cooperated in this study and, by taking samples of the sludge from the unit, has been able to assess the bacterial content and the protosoal content of the sludge. It has been shown that the con-

tent of nitrifying bacteria in the sludge from the UNOX process has not been as high as would be expected from a conventional air activated sludge process and this confirmed the opinions that the sludge age was insufficient for these nitrifying bacteria to develop. Since the change in operation of the system there has been insufficient time for comparative studies of the two sludges to be carried out. A significant difference between the UNOX sludge and a conventional activated sludge was that the UNOX sludge contained a markedly higher proportion of viable organisms. The bacteriological studies on the sludges will be continued and will be reported upon in the final report.

10. In conclusion, there is no doubt that the UNOX plant is capable of removing a very high proportion of the BOD in a short time as low as 2.8 hours in our experiments. The degree of nitrification has not been achieved as much as we had expected but work is proceeding to try to overcome the earlier difficulties experienced in achieving this. The examination of the sludges by the Water Pollution Research Laboratory is an important part of this work. The sludge produced in the UNOX plant is a rapidly settling sludge with good handling characteristics confirming the experience which was found in the USA.

UNION CARBIDE

WIMPEY
UNOX System

REPORT ON THE TEST CARRIED OUT AT THE MUNICH-GROSSLAPPEN SEWAGE WORKS, USING THE OXYGEN AERATION PROCESS

by
Oberbaudirektor F. Karnovsky
München

Introduction

With extending municipal sewerage system, ever increasing water consumption and the connection of the drainage systems of 16 neighbouring communities to the Municipal Sewage Works, the amount of effluent received by the Großlappen Sewage Works is also increasing from year to year. In 1971, total dry-weather flow was about 530 000 m^3/day with the sewage of about 2.3 million inhabitants + population equivalents = 6.3 m^3/sec on a 24-hourly average. The final capacity of the Großlappen sewage works will be 7.5 m^3/sec. This would correspond to a daily inflow of about 650 000 m^3/day and about 3 000 000 inhabitants + population equivalents. Any enlargement of the sewage works is not possible, since the required areas are not available.

In order to estimate the future sewage flow, the municipal authorities responsible for the sewerage system in cooperation with the "Ingenieurgesellschaft X. u. A. Dorsch", Munich, developed in 1966 a prognosis extending to the year 2006. It was based on the town and regional development plan and the corresponding general drainage scheme of the capital of Bavaria, Munich. According to this prognosis, an average dry-weather flow of 7.5 m^3/sec is likely to be reached in 1978. In the year 2006, an average total dry-weather flow of 16.5 m^3/sec. is to be expected on workdays. With a BOD_5 of 270 mg/l in the influent, this gives a value corresponding to about 6 700 000 inhabitants + population equivalents. Since the existing sewage works at Großlappen can only receive a maximum corresponding to about 3 000 000 inhabitants + population equivalents, the wastes of the additional inhabitants + population equivalents must possibly be clarified in two further sewage works.

For the time being, the responsible Bavarian authorities are setting up the general water scheme for the river Isar which goes into the waste problems of the Munich area in detail. In this plan, several alternative schemes of sewage disposal in

the Munich area are provided for the year 2000. They all provide the establishment of sewage works at Dietersheim, using the Isar as the receiving water. These sewage works will be situated about 12 km downstream from Großlappen (Figure 1). The first phase of construction will be terminated in 1978.

According to the decision of the "Bezirksamt München" of 9th Febr., 1933, Bayernwerke AG are permitted to divert from the natural flow of the Isar at the Oberföhringer weir up to 150 m^3/sec of water into their mill race. Accordingly, the entire natural inflow of the Isar in the mill race is on about 305 days of the year utilized for energy production. As a consequence, the flow of the so-called drainage reach of the Isar round about Dietersheim will have a Q_{20} of about 6.0 m^3/sec or not significantly more during a major part of the year, water quality corresponding to "Klasse II" (Standard II). This flow is only maintained by the inflow of ground-water and brooks. The amount of waste to be discharged will, however, be 10.0 m^3/sec ($Q_{24/24}$) with dry weather as soon as the construction of the plant will be terminated.

In view of these facts, it is to be expected that the responsible authorities will from the very beginning subject the new sewage works at Dietersheim to more strict requirements in every respect. For this reason and also because the development of waste purification techniques will not stand still, it appeared to be necessary to start the planning process with several test in order to investigate into new techniques, i.e. the so-called advanced waste water treatment process and new techniques within the framework of conventional processes with a view to Munich wastes.

Objective of the tests

One of the test plants established at Großlappen Sewage Works last year is the aeration plant run with pur oxygen according to the UNOX process. This plant is operated with a view to the following objectives:

1) Testing of the UNOX process, using mechanically treated and untreated wastes.

2) Comparison of the UNOX pilot plant with a conventional type compressed-air plant of similar size, and with similar objectives to be reached.

3) Obtaining sufficient data with regard to design and operation for the development of an alternative aeration plant, using the UNOX process.

In addition to residual pollution of the effluent and oxygen consumption, sludge production and sludge characteristics are of particular interest.

Description of the plant

In order to facilitate thorough and careful continuation of the studies over the winter, an insulated shelter of corrugated sheet with a floor space of 11 x 15 m and a maximum height of 5.5 m was constructed. The UNOX plant, a mobile Schumacher test plant and a Crane microsieve were placed there. The oxygen is placed in the open.

The UNOX plant (Figure 2) covers about half of the total area. Its main part is the gas-tight aeration tank with a working capacity of about 11.5 m^3. The tank is subdivided into 4 stages which are passed successively by the effluent. Each stage is equipped with rotary aerator arms for oxygen supply and a propeller for mixing. The aeration tank is connected with a final settling tank with a capacity of 14.8 m^3, a surface of 4.5 m^2 and slightly inclined bottom. As usual, a scraper is provided for sludge removal (Figures 3,4).

The waste treated in test phases I to IV is taken from the old Emscher tank of the Großlappen sewage works after mechanical purification. It is conveyed to the test plants continuously through a channel equipped with a submersible pump. Before entering the UNOX plant, the effluent is dosed accurately by means of an adjustable spiral-type eccentric pump. To guarantee

reliable operation, an inductometer (Fischer and Porter) is also installed. The effluent from the UNOX plant is fed to the microsieve or directly to the influent channel of the biological plant. Waste water, return sludge and the pure (99 per cent) oxygen are only introduced into the 1st stage. Both, waste and return sludge, are transported by means of spiral-type eccentric pumps with adjustable speed. The excess sludge is also withdrawn continuously, using a hose pump.

Test and monitoring programme

The test programme includes 5 phases, the first 4 phases being run with mechanically clarified waste. The BOD_5 of the waste ranges from 220 - 280 mg/l with peak values exceeding 400 mg/l.

Test phase I :	Aeration period	about 2.5 hours
	desired residual BOD_5	15 - 20 mg/l
	sludge load	0.30 - 0.50 kg BOD_5/ day/kg dried matter
Test phase II :	Aeration period	about 3.0 hours
	desired residual BOD_5	10 - 15 mg/l
	sludge load	0.20 - 0.30 kg/BOD_5/ day/kg dried matter
Test phase III:	Aeration period	about 1.5 hours
	desired residual BOD_5	20 - 30 mg/l
	sludge load	0.60 - 0.80 kg/BOD_5/ day/kg dried matter

Test phase IV : Aeration period varying in accordance with the daily inflow curve to achieve a residual BOD_5 of less than 20 mg/l

Test phase V : The plant is to be run with crude waste withdrawn after having passed screen and sand trap. An aeration period of 1 - 1.5 hours is planned.

In all phases, the amount of return sludge should be 30 to 50 per cent of the influent, and the sludge content 5000 to 9000 g/m^3, while the dissolved oxygen should be maintained at 4 - 10 mg/l.

Monitoring programme

In addition to the recordings for function control and monitoring of given operating parameters, such as influent, return sludge and excess sludge, the following parameters are measured twice daily:

Meter reading oxygen feed
Meter reading waste gas, including pressure and temperature
Hydrocarbon in the gaseous phase
pH-value
Dissolved oxygen
Fraction of oxygen in the gaseous phase

Once a day, influent and effluent pH and oxygen dissolved in the effluent are measured. On weekends and holidays, however, all parameters are only recorded once.

For continuous recording of TOD, two automatic sampling devices were installed (Figure 5) which have only recently been put into operation. The data are printed out on punched tape and can then be evaluated electronically.

In addition, the following analyses are to be carried out:

Site	Type	Workdays	Weekends and Holidays
Influent and effluent	BOD_5	24 h MS	24 h MS
	COD	24 h MS	24 h MS
	TOD	continuous	continuous
	Solids	1 RS	
	Loss on ignition	1 RS	
	Ammonia-N	several	
	Total N	several	
	Phosphate-p	several	
Reactor Stage 1 to 4	Solids	1 RS	
	Loss on ignition	1 RS	
Reactor Stage 4	Settlement test	1 RS	1 RS
	Sludge index	1 RS	-
Excess sludge	Solids	1 RS	1 RS
	Loss on ignition	1 RS	-
	Settlement test	1 RS	1 RS
	COD	1 RS	1 RS

MS = mixed sample
RS = random sample, daily

Proceedings of the tests, first results, experience gained with regard to operation

The test plant was put into operation early in October 1972. It was inoculated with 1 m^3 of 0.8 per cent activated sludge (index: about 80 cm^3/g) from the large-scale plant. This inoculation with sludge from a different system has proved to be an error. More than one month we tried in vain to cope with increasing amounts of foam formed more and mor frequently. It was alternately obstructing the rotameters of the various stages and the oxygen compressors and finally even entered the plastic hoses connected with the gas sampler. The attempt of coping with the situation by using a defoaming agent turned out to be a complete failure. So, in the end, there was no other choice than emptying the plant and starting the whole process again, this time without using foreign sludge. Despite of the rather low effluent temperature of about 12 °, the initial operation period required was surprisingly short. Already after 7 days, a sludge content of 4 g/l was obtained in the aeration tank. After about 18 days, the plant was in full operation. Although the sludge load remained unchanged, no foam was produced any more.

The tests showed that the activated sludge does not contain any filamentous bacteria. Significantly improved settlement characteristics were obtained.

The supernatant grease in the central tube of the final settling tank, though not being an alarming phenomenon, should be given attention. A smal funnel to receive the grease collected by hand, connected with a pump, would be required.

Not only was it rather easy to replace individual parts of the equipment, such as gas meters or valves, but also did the mechanical as well as the monitoring systems work faultlessly.

Supersvision of the plant

On workdays, the plant is supervised by a technician during one shift and maintained in accordance with a check list. Five members of the staff of the municipal sewage service volunteered for the control service on weekends and holidays. This includes checking all important functions, recording the measured data, and drawing the required samples. For particular incidents, an alarm plan was prepared.

Results obtained so far

The results reported here are intermediate results of test phase I. All means were abtained from 22 individual values. The detention period was always 2.4 hours, corresponding to an influent of 4.6 m^3/h and a space load of 10 $m^3/m^3/day$. Influent and effluent pollution as well as removal efficiency are shown in Figure 6.

Remarkable variations in influent parameters have been noted. BOD, for example, deviates from the mean of 270 mg/l by about $\pm$ 50 per cent, COD by about $\pm$ 35 per cent from the mean of 420 mg/l. These relatively marked deviations (BOD: about 270 mg/l, COD: about 290 mg/l) are hardly perceptible in the effluent.

The following means wer determined:

BOD_5 = 13 mg/l (not less than 6 mg/l, not more than 30 mg/l)
COD = 65 mg/l (not less than 40 mg/l, not more than 82 mg/l)

Average removal was

BOD_5	95 per cent
COD	84 per cent

For the suspended solids the following means were determined:

Influent	170 mg/l
Effluent	15 mg/l
Removal	91 per cent

Figure 7 shows several operating data:

Average sludge content	7.2 mg/l
Average solids content of return sludge	2 per cent
Average sludge index	38 cm^3/kg

For the settlement tests, an agitator was employed. Relatively slight variations were recorded.

Further interesting means are:

Temperature of the waste	12 °C
Dissolved oxygen	13 mg/l
BOD space load	2.74 $kg/m^3/day$
BOD sludge load	0.38 kg BOD_5/day/kg dried matter
Utilization of oxygen	95 per cent
Loss on ignition, excess sludge	68 per cent

The first test phase will be run for about another month. The results mentioned here cannot be regarded as final. It is too early as yet to draw any conclusions after a test period of only one month.

The mobile test plant from Schumacher is also placed in the shelter (Figure 8). This plant is to be used for parallel tests. Experience, however, showed, that parallel operation of the UNOX and Schumacher plants, for example with exactly equal amounts of sludge, will fail because of the technical and operating problems involved. The two plants are therefore operated separately now, yielding about equal residual pollution loads.

Conclusion

The test using the UNOX plant will cost the City of Munich about 300 000 DM. Therefore, it was considered for a long time, whether the same results could not be achieved at lesser cost with a smaller test plant. Since reliable data on sludge production and sludge characteristics and really clear and re-

presentative data on the UNOX process were required, this large plant was chosen. It will also provide the most reliable basic data for the alternative design of a large-scale plant using oxygen aeration.

PRELIMINARY RESULTS OF PARALLEL TEST WITH FINE BUBBLE AERATION AND OXYGENATION BY THE LINDOX PROCESS

by
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In summer 1972, a pilot plant, using the LINDOX process, a method of oxygen aeration developed by LINDE AG, was established on the test site of the Bayerische Biologische Versuchsanstalt. For some time now, LINDE AG has investigated into the use of industrial oxygen in the activated sludge process. After having tested the process on laboratory scale, LINDE developed mobile test units. Upon consultation with the Bayerische Biologische Versuchsanstalt, a stationary plant was established on the test site for waste water purification.

Parallel tests, using common conventional processes, were regarded as an important prerequisite for obtaining representative results, since only parallel test using the same waste water, the same size of aeration and final settling tanks and the same temperatures give an overall impression and allow direct comparison with oxygen aeration. For the parallel test, a process particularly suitable for comparison, with fine bubble aeration according to Schumacher was chosen. It has already been used with advantage for the treatment of Munich waste water (Figures 1 and 2). The Bayerische Biologische Versuchsanstalt employed for their tests two activated sludge tanks of equal size and the corresponding final settling tanks. The test unit developed by LINDE AG consists of an aeration tank equipped with a special cover (Figure 3). Industrial oxygen is introduced into this tank by means of a compressor and contacted with the water-sludge mixture (see "The Use of Industrial Oxygen in the Activated Sludge Process, by Liebmann and Scherb). The excess oxygen is sucked off by the compressor again. An amount of oxygen corresponding to the amount of oxygen utilized in the process is fed to the system from an oxygen source. Part of the gas is allowed to excape into the atmosphere, so that the amounts of inert components, such as the N_2 and the CO_2 present in the system are limited. The water-sludge mixture in the aeration tank ist stirred opposite to the direction of the stream of oxygen by means of a paddle mechanism. In principle, the LINDOX system is an agitator unit with the oxygen being distributed at a low level of the tank. The required oxygen is supplied from an oxygen tank with a capacity of almost 5 m^3 and from a conventional double-walled va-

cuum bottle equipped with the fittings, regulating and measuring devices required for fully automatic operation.

The aeration tank established on the test site is connected with a final clarifier in the form of a Dortmund tank with a capacity of 25 m^3.

The test plant was fed with municipal waste from Munich that had passed primary clarification at the Munich sewage works.

In the following, findings and results of two test phases of 1972 will be given.

The tests were carried out with detention periods of 2 hours, load per volume ranging from 2.7 to 2.9 kg BOD_5/m^3/day, and sludge load ranging from 0.89 to 0.90 kg BOD_5/kg dried matter/day. The average BOD_5 of the waste was 212 mg/l (test phase A) and 241 mg/l (test phase B).

Test A: Treatment with pure (96 per cent) oxygen
Test B: Treatment with an air-oxygen mixture, containing about 50 per cent O_2

Test A

In Test Phase A, the water-sludge mixture was treated with a mixture of pure (about 99 per cent) oxygen, the sludge concentration was 3 - 4 g/l, and a mean oxygen content of 10 mg/l was aimed at. In the conventional plant used for the parallel tests, an oxygen content of 2 - 4 mg/l was maintained.

Table 1 shows characteristics and results of operation. With a BOD_5 load per volume of 2.7 kg/m^3/day and a sludge load of 0.893 to 0.895, a reduction in BOD_5 of about 92.5 per cent was achieved in both plants. The COD decreased by 79 - 80 per cent, and an effluent COD of 75 and 80 mg/l, respectively, was obtained. The effluent BOD_5 ranged from 16 to 17 mg/l.

In all tests, the sludge obtained in the LINDOX unit showed

favourable settlement characteristics, the average sludge index was 78, and thus lower than with conventional treatment, where values between 100 and 130, i.e. an average of 118, were measured. When calculating the amount of excess sludge, care was taken to include the sludge particles and other suspended solids contained in the purified waste. For this purpose, the effluent was filtered through a filter membrane with both treatment methods. The amount of excess sludge produced in the conventional aeration process was only slightly higher than in the oxygenation process.

With the oxygenation method, a biological community developed in the activated sludge which was at times slightly different from that of the conventional process with regard to quality and quantity. The occurrence of fungi in the activated sludge was a characteristic phenomenon (Figure 4) which had no unfavourable effect on settlement characteristics.

The filamentous bacterium Sphaerotilus natans was also present in the biological community, but on the whole, did not develop in major amounts. A number of other organisms were found in addition to the bacteria, ciliates being noted frequently. The ciliate Opercularia coarctata was always present. Vorticella convallaria and Aspidisca costata were also found. Other members of the biological community were various amoebae and flagellates as well as nematodes. The sludge flocs are of more compact or granular appearance as compared with those obtained in the conventional aeration process.

In the activated sludge of the conventional type plant, no fungi were found. The zoogloeae always contained some filamentous bacteria as are also found in other sludges produced in the sewage plants on the test site. The sludge obtained showed the characteristic pattern of a highly polluted activated sludge (Figure 5).

The activity of the activated sludge was determined every week. It was slightly different in the two processes. With the oxygenation process, it was about 0.253 kg O_2/kg of dried matter/day on an average, while with the conventional process it was

0.11 kg O_2/kg of dried matter/day on an average.

The nitrogen and phosphorous compounds contained in the effluent and influent were also determined each time. No differences were noted between the two processes with regard to the decrease in phosphorous content. Decrease in ammonium and organic nitrogen were also similar; nitrification did not occur to any significant degree in any of the two processes.

Test 3

In test phase 3, the activated sludge was treated with a gaseous phase containing 40 to 50 per cent of O_2, while the sludge concentration was 3 - 4 g/l. The other parameters, except for oxygen content in the activated sludge tank, were almost equal. Table 7 shows the characteristics and results of operation. In this test, too, BOD_5 and COD removal were about equal in both plants. In the course of the investigations, sludges with varying settlement characteristics were produced in both plants; the average sludge index was 151 and 177 ml/g, respectively. Microscopy showed the increased occurrence of sphaerotilus natans. Since the activated sludge could not be determined reliably because of the high sludge index, the determination of the amount of excess sludge produced was quite a problem.

The other tests to be carried out on the test site at Großlappen will serve to investigate into the operation of the plants with high sludge concentrations.[7] A wide variety of differing operating conditions is possible. Ultimately, the optimum conditions of operation have to be determined for each individual oxygenation plant.

For special investigations, a second oxygenation plant, using the LINDOX process, is available. This plant is primarily used for tests on industrial wastes and various components of waste water. Industrial waste is added to the municipal waste from Munich or also introduced into the plant undiluted in

order to obtain an objective and comprehensive an insight into the suitability and practicability of oxygen aeration in the activated sludge process as possible; the tests are particularly interesting with regard to industrial wastes. The research project is being supported by the Bayerisches Staatsministerium für Landesentwicklung und Umweltfragen (Bavarian Ministry for Environmental Questions and Regional Planning).

Figure 6 shows the mobile test unit. It is mounted on a support and consists of an aeration tank with a working capacity of 2 times 0.5 m^3, a final settling tank with a working capacity of 2 m^2 and an adjustable overflow weir, pumps for transporting effluent and sludge, a gas circulation compressor for the compression of oxygen and devices for measuring and control. The oxygen is fed from liquid oxygen bottles.

LINDE AG has several plants of this type which may also be used in joint operation. Thus it is possible also to investigate into the two-stage or multi-stage activated sludge process with intermediate clarification under varying conditions with regard to the aeration period of the first and second stages, etc.

Note:
After the seminar was terminated and these lines were printed, further tests have been carried out.
The detention period of the waste in the activated sludge tank was 3.3 hours; sludge concentration was increased to 6 - 7 g/l. In this case, too, both processes yielded approximately similar BOD_5 removal. Differences between oxygen aeration and conventional aeration processes were noted with regard to the amount of excess sludge produced. In the oxygenation process it was 10 - 20 per cent lower on an average; the tendency towards smaller amounts of excess sludge was particularly evident when the sludge age exceeded 6 days.
Further tests are being conducted with dairy wastes and the wastes from a knackery.

Table 1

Test plant		Oxygen aeration	air aeration
Aeration period	h	2	2
BOD_5 load per volume	$kg/m^3/d$	2.7	2.7
Sludge load	kg/kg/d	0.695	0.693
	kg/kg dried matter/day	0.950	0.950
Dry weight of sludge	kg/m^3	3.76	3.72
Sludge index *)	ml/g	78	118
Oxygen content	mg/l	10	3
Influent BOD_5	mg/l	212	212
Effluent BOD_5	mg/l	17	16
Decrease	per cent	92	92.5
Influent COD	mg/l	379	379
Effluent COD	mg/l	80	75
Decrease	per cent	79	80
pH, influent		7,57	7.57
pH, effluent		6.91	7.62
Water temperature			
influent	°C	13.8	13.8
effluent	°C	13.6	13.4
O_2-consumption per BOD_5-removal	kg/kg	1.00	1.06
Utilization of O_2	%	93	ca.10
Excess sludge per BOD_5 removal	kg/kg	0.90	0.915

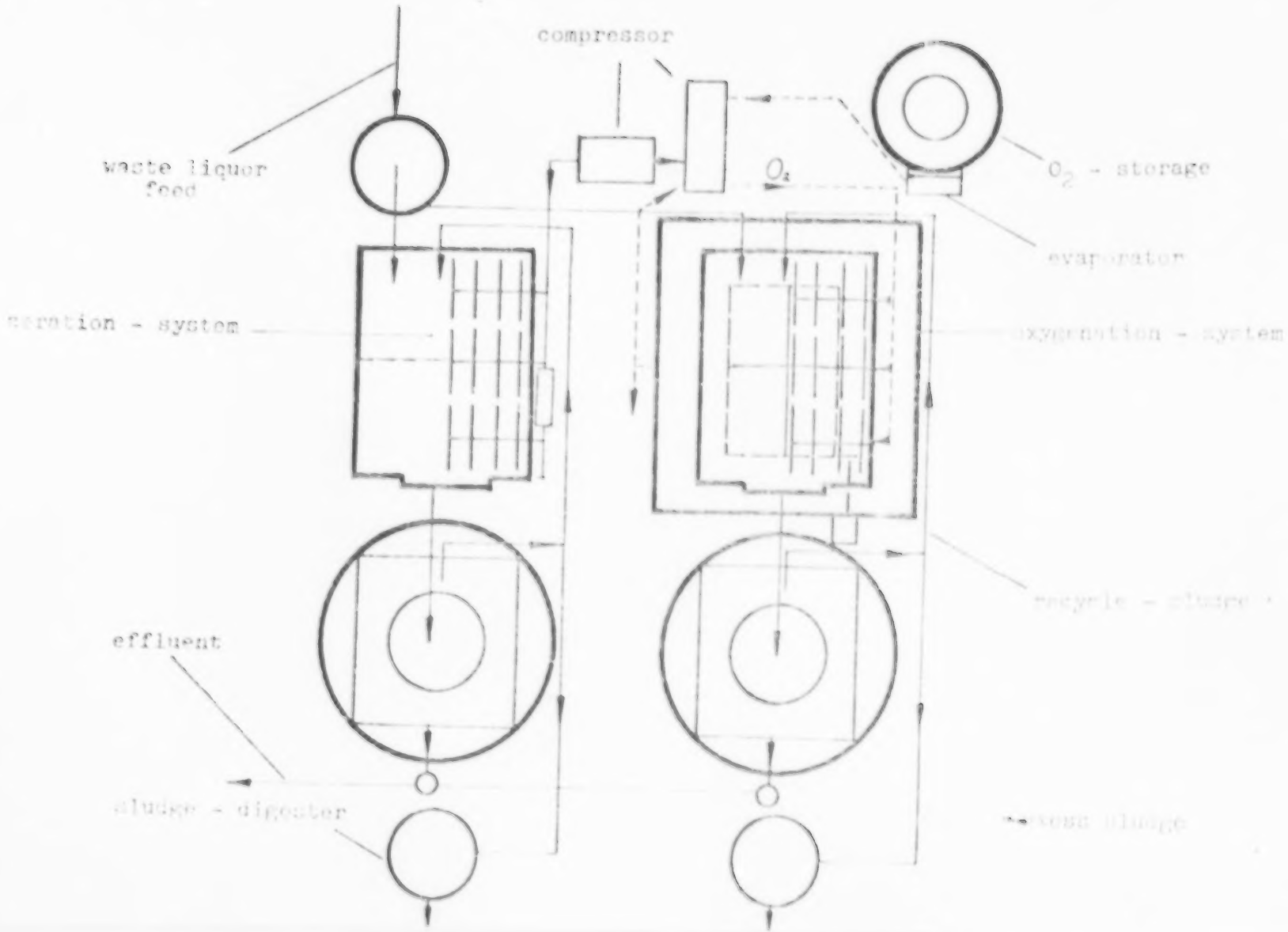
*) determined as sludge volume index, without stirring and diluting

Table 2

Test plant		Oxygen aeration	air aeration
Aeration period	h	2	2
BOD_5 load per volume	$kg/m^3/d$	2.9	2.9
Sludge load	kg/kg/d	0.906	0.811
	kg/kg dried matter/day	1.33	1.11
Dry weight of sludge	kg/m^3	3.4	3.8
Sludge index *)	ml/g	177	191
Oxygen content	mg/l	10	3
Influent BOD_5	mg/l	241	241
Effluent BOD_5	mg/l	18	18
Decrease	per cent	92.5	92.5
Influent COD	mg/l	430	430
Effluent COD	mg/l	75	72
Decrease	per cent	82.6	83.3
pH, influent		7.45	7.45
pH, effluent		7.11	7.65
Water temperature			
influent	°C	16.3	16.3
effluent	°C	16.6	16.5
O_2-consumption per BOD_5-removal	kg/kg	0.96	1.08
Utilization of O_2	per cent	85	ca.10

*) determined as sludge volume index, without stirring and diluting

Fig. 1 Schematic Diagram of the test plant



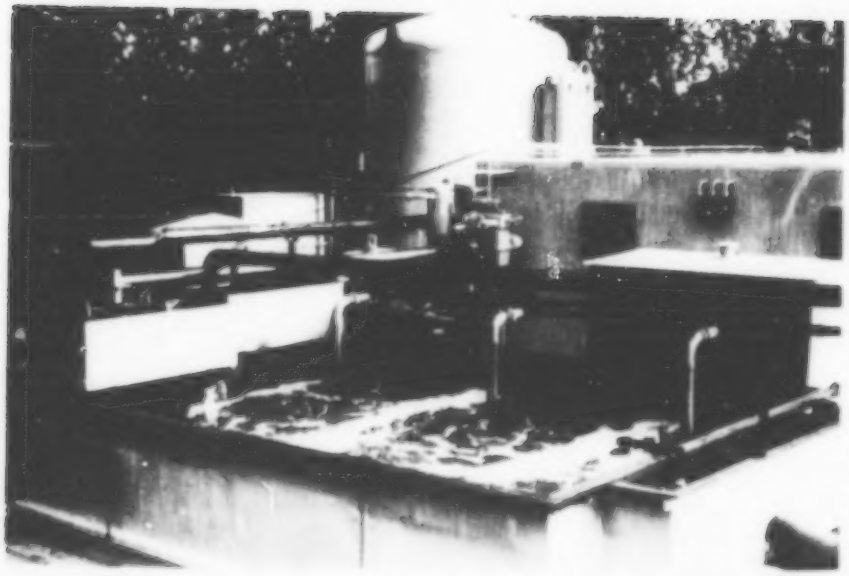
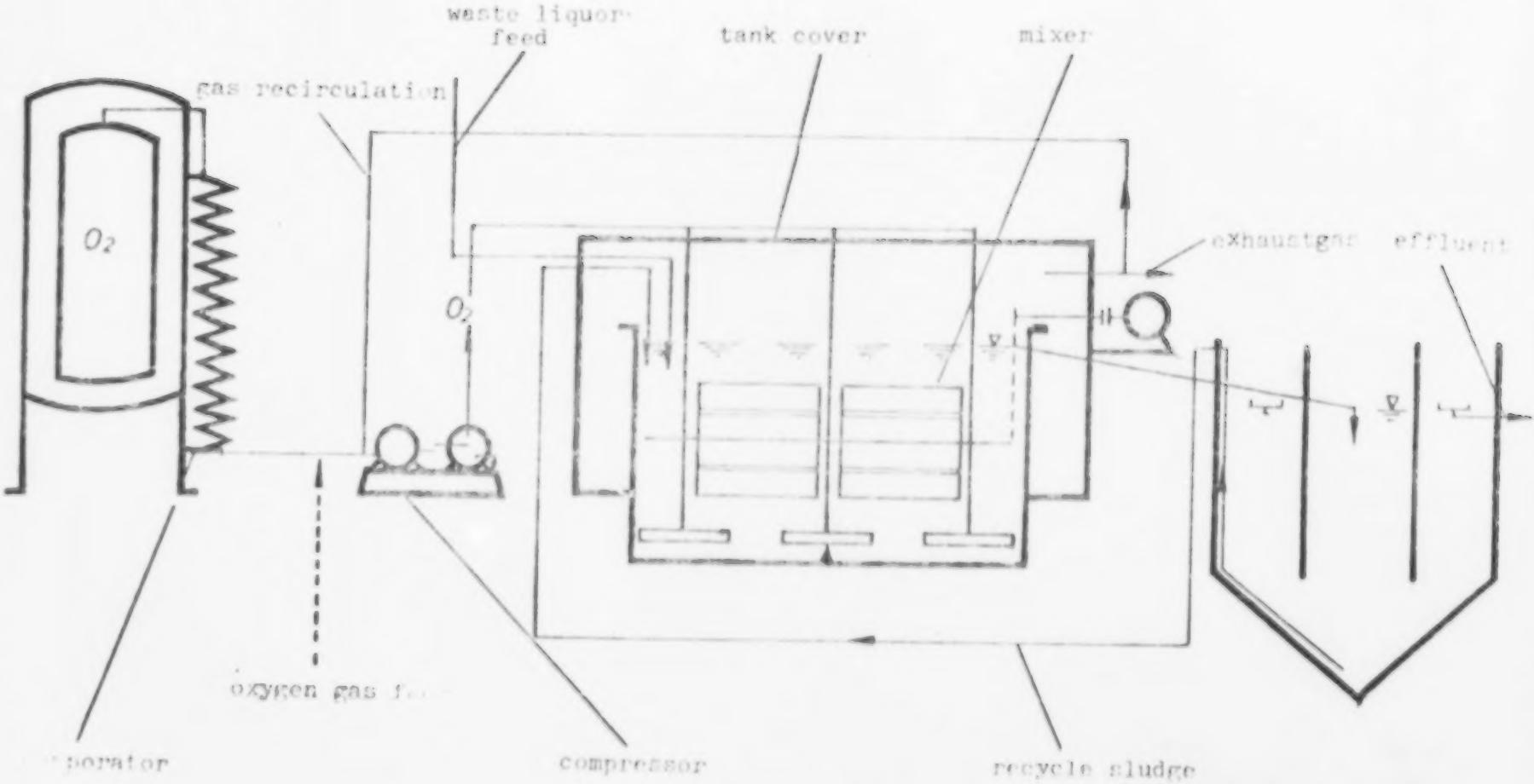


Fig. 2 View of the testplant; the conventional plant with fine bubble aeration in the foreground, the Lindox - plant in the background

Fig. 3 O_2 LINDOX - SYSTEM



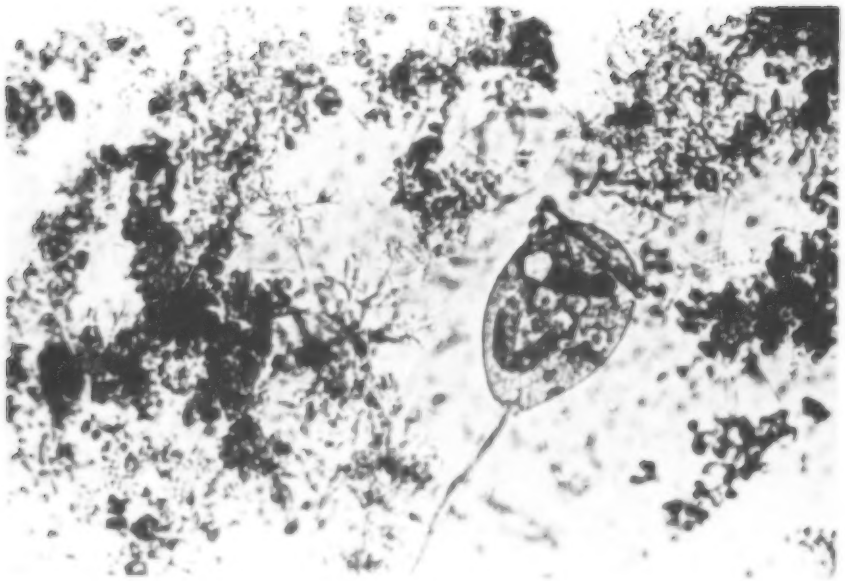


Fig. 4 The biocenosis in case of aeration with technical oxygen

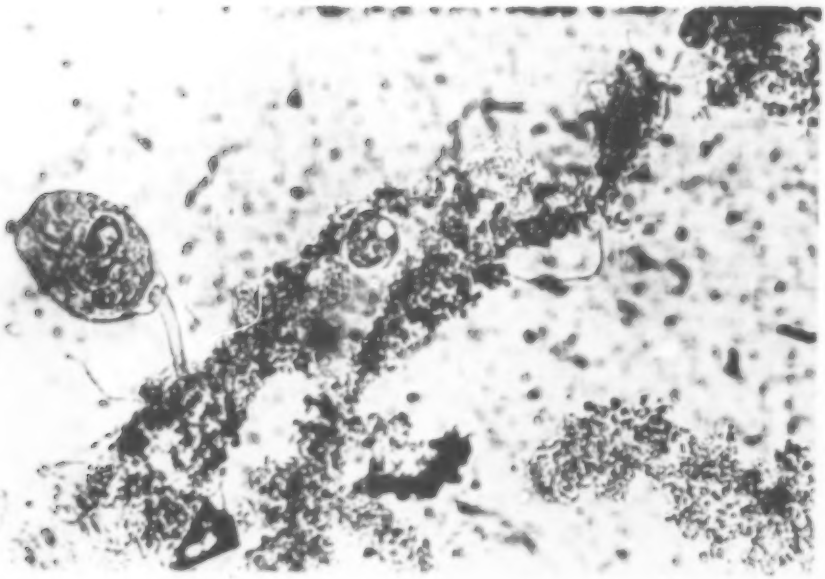


Fig. 5 The biocenosis in case of converntional aeration

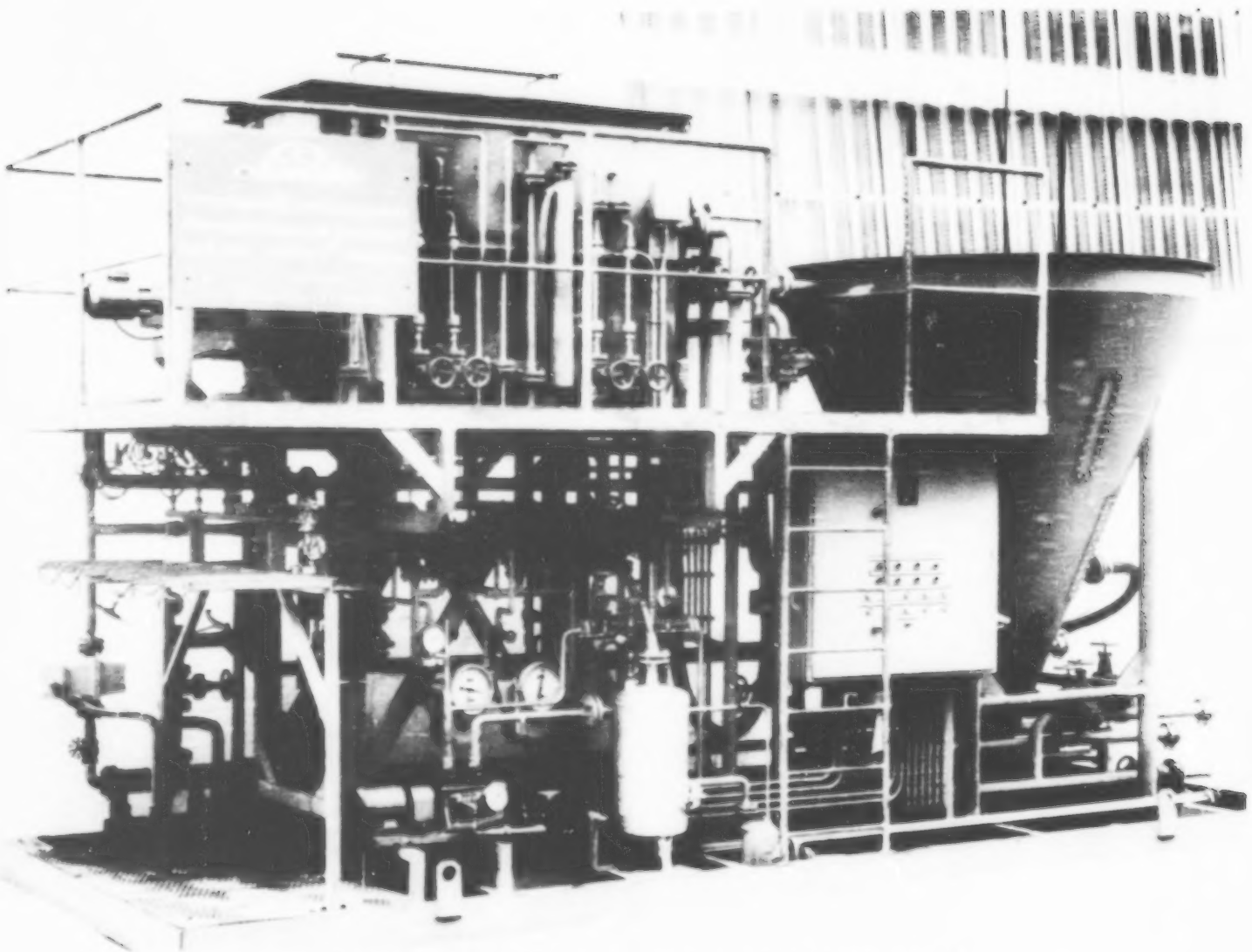


Fig. 6 Mobil biological waste water treatment plant with oxygenation by LINDOX-System, Linde A.G. Munich

L'EPURATION BIOLOGIQUE DES EAUX
A L'AIDE D'OXYGENE PUR OU D'AIR ENRICHI
TRAVAUX FRANCAIS

de
Dominique Larré
Paris

Les problèmes posés par l'utilisation de l'air en épuration biologique des eaux ont conduit à rechercher les avantages de l'oxygène pur et de l'air enrichi et à tenter de mettre en oeuvre des procédés nouveaux et originaux dans ce domaine.

Les objectifs.

Les équipes de recherche françaises se sont attachées à résoudre les problèmes suivants:

- suppression de l'incidence du ballast en gaz inertes lors de l'utilisation de l'air.
- difficulté du maintien de hautes teneurs en oxygène dissous
- accroissement de l'efficacité des bassins actuels en particulier par l'augmentation des concentrations en boues activées
- adaptation des stations aux à-coups de charges caractéristiques des conditions modernes de rejet des eaux résiduaires tant urbaines, qu'industrielles ou mixtes.

En outre, on s'est fixé come objectif de proposer une technologie aussi simple que possible permettant de ne pas envisager de modifications fondamentales de l'ingéniérie actuellement utilisée.

Les resultats obtenus

Les recherches préliminaires ont permis de montrer:

- que la manipulation de gaz purs était parfaitement envisageable dans des conditions de sécurité normales.
- que l'efficacité de l'épuration était accrue par les facteurs suivants: le maintien d'un haut niveau d'oxygènation n'ayant pas pour corolaire une dégradation de la qualité physique des boues, la possibilité de faire face à des à-coups de pollution sans affecter les qualités de décantabi-

lité de la boue, le maintien de hautes concentrations en boues activées favorisant la réduction des volumes.

- que l'énergétique des systèmes était largement réduite et que le gain était d'autant plus grand que la quantité de pollution traitée s'accroissait.
- que l'utilisation de l'oxygène pur ou de l'air enrichi pouvait être envisagée de façon simple avec des rendements compatibles avec les exigences économiques du traitement des eaux résiduaires.

Ces recherches ont conduit à la réalisation d'expérimentations sur un pilote. Les caractéristiques de ces expérimentations sont les suivantes:

- conditions imposées:
  - . égout réel présentant des pointes de pollutions atteignant quotidiennement 200 % voire 300 % de la valeur moyenne (entrée du bassin biologique).
  - . réduction de la pollution assurant un rejet conforme aux exigences légales et dans tous les cas avec réduction supérieure à 90 %.
- conditions du dimensionnement:
  - . volume du bassin biologique: échelle semiindustrielle 5 à 10 m^3
  - . conditions de l'introduction du gaz: géométrie et profondeurs utilisées dans les stations à l'air.
- conditions de réalisations de l'ingéniérie:
  - . matériaux utilisés en stations à l'air (bétons et aciers ordinaires)
  - . matériels couramment utilisés par l'air.

Ces conditions ont été imposées en vue de permettre une extrapolation aisée pour des stations de dimensions industrielles et surtout pour permettre une comparaison significative avec l'utilisation de l'air atmosphérique.

Les résultats obtenus à ce jour sont suffisamment prometteurs

pour permettre d'envisager sans difficultés particulières le passage à des installations pilotes à grande échelle.

Conclusion

Sur la base des résultats obtenus pour les essais en cours, il apparait que des idées originales doivent permettre de réaliser des bassins d'épuration biologique utilisant l'oxygène pur ou l'air enrichi travaillant en un seul étage de traitement (identiquement aux stations actuelles) et permettant une réduction de la pollution organique conformément aux exigences de la législation tout en garantissant une utilisation de l'oxygène d'au moins 90 % et une réduction des dépenses énergétiques suffisante pour ne pas affecter les frais d'exploitation.

Sur le plan du fonctionnement, il est d'ores et déjà montré qu'une surcharge atteignant 2 à 3 fois la charge nominale pourrait être acceptée sans accroissement correspondant des dépenses énergétiques et surtout garantissant le maintien des qualités physiques de la boue et la qualité de l'épuration.

ETUDE DE L'EPURATION BIOLOGIQUE AVEC AERATION A L'AIR ENRICHI EN OXYGENE

de
Dominique Larré
Paris

En plus des éléments connus de la littérature internationale et particulièrement américaine sur le sujet, la cinétique d'assimilation des boues activées concentrées a été testée en France au laboratoire, avec des concentrations de 6 à 30 g/l.

Cette recherche, menée en 1970-1971, a permis de démontrer que pour les boues peu concentrées l'intérêt de l'oxygène pur est médiocre mais que, pour des boues ayant une concentration supérieure à 10 g/l, la combinaison d'une aération à l'oxygène pur ou à l'air enrichi et d'une agitation mécanique iutense permettait d'accroître les rendements d'oxygénation.

Par ailleurs, lorsque l'on faisait travailler ces mêmes boues concentrées à forte charge de pollution, l'avantage était trés net quant au rendement d'épruation, et la conclusion de cette étude était que l'emploi de l'oxygène pur ou de l'air enrichi convenait particulièrement pour le traitement en un ou plusieurs stades d'eaux résiduaires fortement concentrées et permettait de réduire considérablement la taille globale de la station d'épuration.

Il ne semblait donc pas nécessaire de reprendre plus avant des études de laboratoire ou sur un pilote semi-industriel de taille par trop réduite et qui ne permettraient de donner que des résultats purement qualitatifs.

Par contre, avant de passer à une première réalisation de taille industrielle, il a paru utile d'effectuer une expérimentation pilote avec un dimensionnement d'installation suffisant pour assurer un fonctionnement continu et pour permettre d'obtenir des résultats quantitatifs et d'extrapoler les renseignements technologiques à des appareillages en vraie grandeur.

Nous avons pensé qu'il était nécessaire d'installer un tel pilote dans des conditions réelles d'emploi, c'est-à-dire traitant une eau résiduaire industrielle non synthétique, avec toutes les variations possibles en quantité et en concentration que l'on peut rencontrer dans la pratique.

Après contact avec l'Agence de Bassin RHIN-MEUSE, nous sommes dirigés vers le choix d'une eau résiduaire de laiterie-froma-

gerie qui a pour caractéristiques:

- une forte concentration en pollution: DBO_5 comprise entre 1000 et 2500 mg/l,
- une faible concentration en matières en suspension et en débris grossiers, ce qui facilite les essais sur pilote de dimensions assez réduites,
- généralisation assez aisée pour les nombreuses unités industrielles produisant des rejets semblables.

Le choix du site s'est donc porté sur une usine du groupe Lorraine Lait à CONS-la-GRANVILLE, à proximité de Longwy.

Description de la station pilote projetée

La station pilote proposée comporte trois parties principales:

. un ensemble de cellules d'aération

. un flottateur

. deux clarificatuers

Cet ensemble permettrait de multiples combinaisons:

1) Traitement biologique en un seul stade avec boues activées aérées à l'air enrichi en oxygène et séparation des boues par flottation (Schéma 1).
2) Traitement biologique en un stade avec aération à l'air enrichi en oxygène, et séparation des boues activées par flottation, plus traitement de finition de l'eau épurée par post-clarification (Schéma 2).
3) Traitement biologique en un seul stade avec aération par air enrichi en oxygène et séparation des boues activées par clarification seule (Schéma 3).

Le pilote sera conçu de manière à pouvoir fonctionner avec les schémas 1 et 3 en parallèle, d'où une comparaison des deux procédés dans des conditions scientifiquement valables.

4) Traitement biologique en deux stades:

   . premier stade: boues activées aérées à l'air enrichi à l'oxygène et séparées par flottation,

   . deuxième stade: boues activées aérées à l'air atmosphérique, séparation par clarification (Schéma 4).

5) Traitement en parallèle d'une part avec air enrichi à l'oxygène et d'autre part aération à l'air atmosphérique, afin de comparer les deux techniques.

Dimensionnement du pilote

Le pilote sera conçu pour traiter environ 100 kg de DBO_5 par jour.

Partant d'une concentration de 2000 mg/l de DBO_5 dans l'eau à traiter, il sera donc prévu pour un débit journalier de 50 m^3.

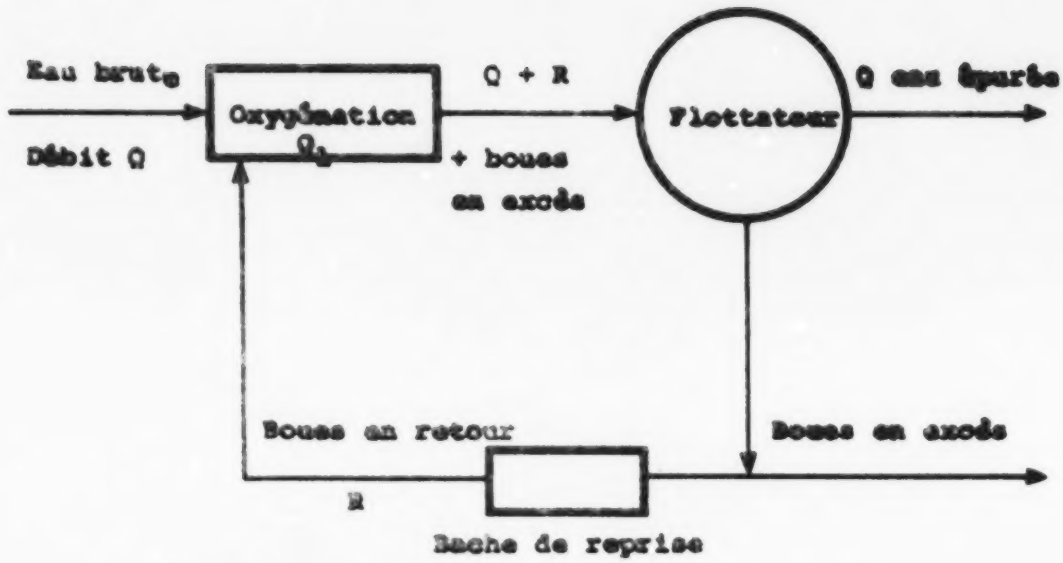
Les bassins d'aération comporteront cinq chambres de 2 m^3 de capacité utile chacune, permettant de faire varier les temps de séjour de une à cinq heures et de travailler en un ou deux stades.

Bien entendu, l'intérêt d'un tel pilote est de tester non seulement le processus biologique, mais aussi le matériel de production d'air enrichi en oxygène. Le pilote est donc prévu pour fonctionner soit à l'oxygène pur à partier de containers, soit à l'air enrichi à l'oxygène produit par la technique des tamis moléculaires.

Planning de réalisation de l'etude

L'éxécution de ce pilote est prévue pour le premier trimestre 1973 et sa mise en route se fera en Avril-Mai 1973. Il est prévu une durée totale d'essai d'un an.

Schéma n° 1



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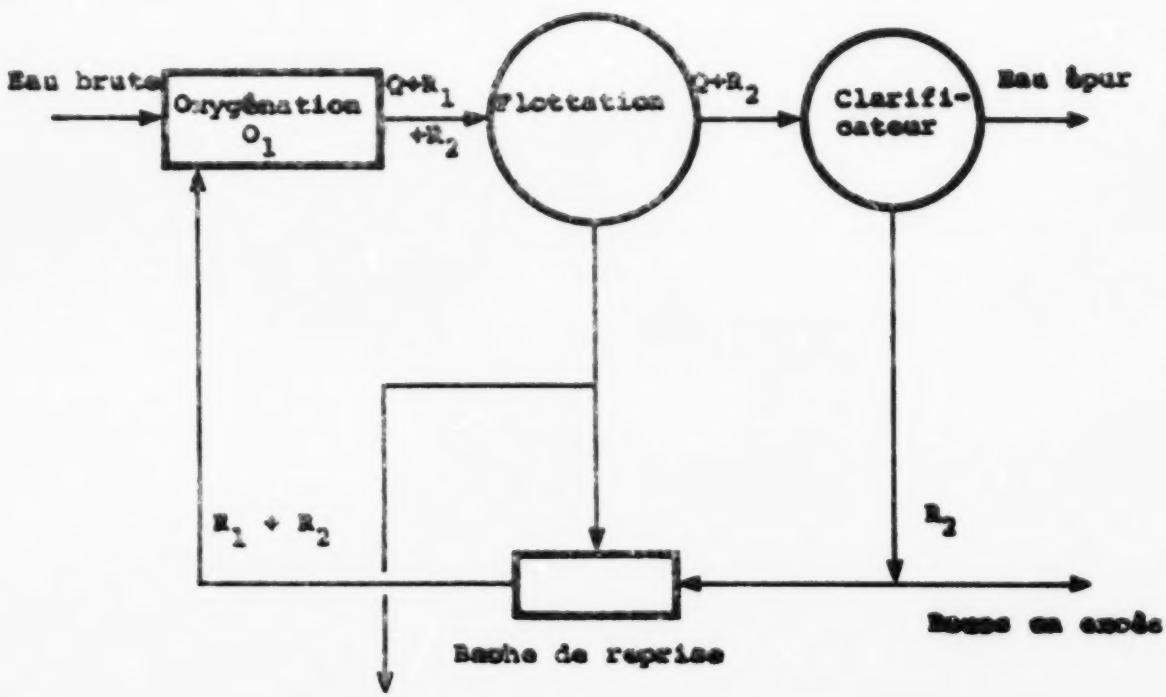

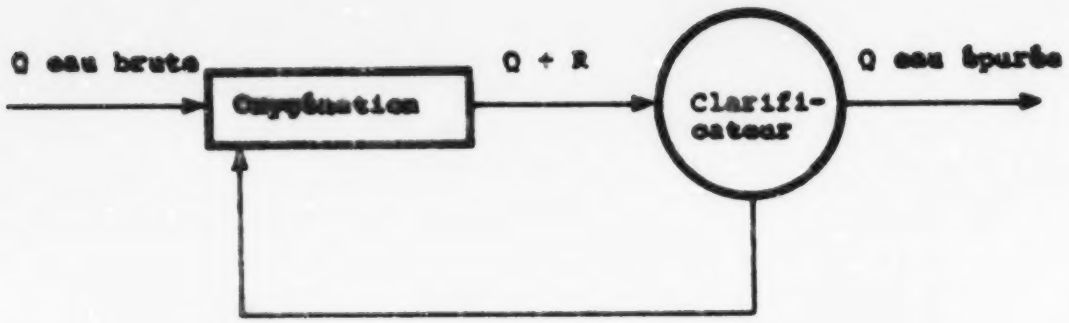

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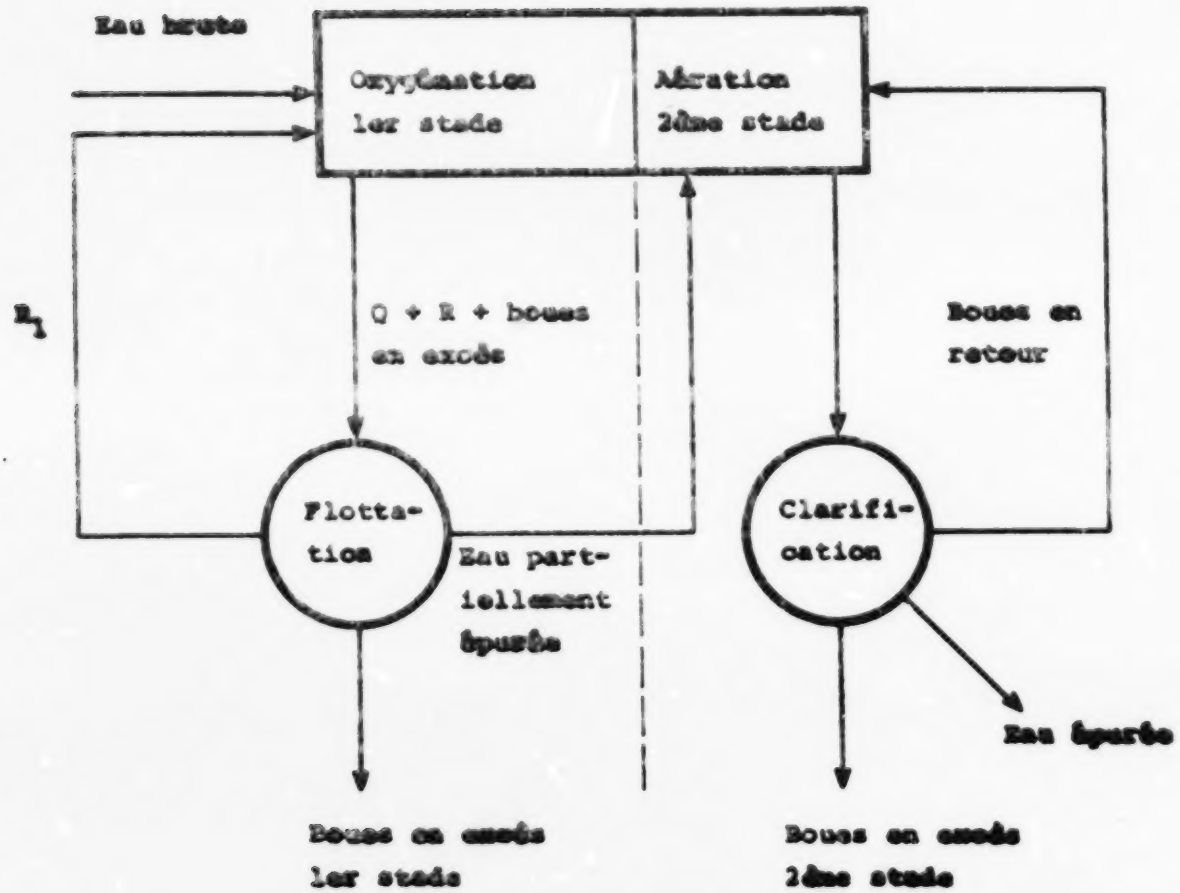

Schéma n° 4

SUMMARY AND PROSPECTS

by
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The use of industrial oxygen instead of air in the activated sludge process was already considered several decades ago in the United States and in Germany. These investigations, however, did not go beyond laboratory scale, since the technical means available at that time did not allow adequate utilization of the oxygen feed so that this process was less efficient than conventional aeration techniques. Only in the last few years has this approach been taken up again, particularly by intensive research work done in the United States, and developed to technical practicability. The results of these experiments showed the following advantages of oxygen aeration:

1. Since the partial pressure of pure oxygen is 4.8 times higher than that of atmospheric oxygen, a correspondingly high oxygen level can be maintained in the aeration tank. (When oxygen is used, it is possible to maintain concentrations of >7 mg O_2/l with only slightly more efforts to be devoted to dissolving the feed gas, while the use of air involves the consumption of uneconomically large amounts of energy.)
2. The high oxygen level allows increased sludge concentrations in the aeration tank, with the specific removal efficiency of the sludge not being impaired. This results in a higher pollution load capacity per space unit, i.e. smaller tanks may be used than in the conventional aeration process.
3. With pure industrial oxygen, a degree of utilization of up to 90 per cent is possible. The volume of the oxidant, being rather low anyway, is further reduced to a large extent in the course of this process, so that the resulting waste gas is only about 1 per cent of that produced in the conventional process.
4. The use of oxygen allows adjusting the gas feed to a wide range of varying loads without much additional equipment being required.
5. When oxygen was used instead of air, decreased amounts of

excess sludge were produced and sludge characteristics were improved.

Recently these results induced various European institutions to investigate into the technical possibilities of the use of oxygen in the activated sludge process.

The investigations of the Wupperverband started early in 1972 with the establishment of a pilot plant run according to the UNOX process. It was the objective of these investigations to find out, whether this process may be used for wastes with a high percentage of industrial effluent, which tend to emit unpleasant odours because of their easily volatile components. During the tests with varying loads, a sludge concentration of 5 - 6 g/l could be maintained in the aeration tank, allowing a BOD_5 load per volume of 1.7 - 1.8 kg/m^3/day inspite of the unfavourable composition of the waste. With a sludge load of 0.3 kg BOD_5/kg dried matter/day, the required effluent quality of 25 mg BOD_5/l was obtained after an aeration period of 6 hours, while with the conventional aeration process, about double the reactor volume was needed for yielding the same results. Sludge characteristics were significantly improved as against compressed-air aeration. Waste air and sewage plant effluent were largely free from unpleasant odours.

Parallel to the investigations of the Wupperverband, Farbenfabriken Bayer, Wuppertal/Elberfeld, conducted tests on their highly concentrated chemical wastes in a semi-technical two-stage test plant using the UNOX process. While with the conventional process an aeration period of about 16 to 17 hours was required to reduce BOD_5 from about 2000 mg/l to a residual effluent concentration of 40 mg/l, a reaction time of only 9 hours was sufficient in the oxygen aeration process to obtain the same results. Solids concentration was 8 - 9 g/l in the first stage, and 7 - 8 g/l in the second stage. In this case, too, improved sludge characteristics and reduced amounts of sludge were observed when oxygen was used.

The test plant of the City of Munich at the site of the Großlappen Sewage Works is also run according to the UNOX process.

It is fed with primarily domestic waste and is used for the determination of the parameters for a project alternative to the conventional type, with a view to a new sewage plant to be established. With a load per volume of 2.7 kg $BOD_5/m^3/day$, a mean sludge content of 7 g/l and an oxygen content of 13 mg/l, BOD_5 was reduced from 270 to 13 mg/l, COD from 420 to 65 mg/l, and suspended solids from 170 to 15 mg/l. The sludge index of 38 indicates very favourable sludge characteristics.

On the test site of the Bayerische Biologische Versuchsanstalt in Munich, a test plant run according to the LINDOX process is operated parallel to a conventional plant of equal size using fine-bubble compressed-air aeration. While with the UNOX process, a multi-stage cascade-type reactor is employed as aeration tank, the LINDOX process employs a thoroughly mixing one-stage tank. With pure industrial oxygen, a load per volume of 2.7 kg $BOD_5/m^3/day$ and a sludge content of 3 - 4 g/l, no significant differences in removal efficiency were noted, although, when oxygen was used, the sludge index was significantly lower, slightly smaller amounts of excess sludge were produced, and an oxygen utilization of more than 90 per cent was obtained.

In Great Britain, the oxygen aeration process is being tested at several sites. On of the plants is run at Rotherham according to a process developed by Ames Crosta. A further plant, operated according to the SATEC process at the Davey-Hulme Sewage Works, is being used for primarily domestic waste, and will later also be used for tests on industrial wastes. An extensive research programme for municipal wastes with a high percentage of industrial components is carried out at the Ray-Hall Sewage Works in Birmingham, using a UNOX plant. So far, results are only available from the latter plant. The BOD_5 of the municipal waste with a high percentage of industrial effluent and a sludge content of 5 - 9 g/l was reduced from 280 mg/l to less than 15 mg/l. Since the degree of nitrification required in Great Britain could at first not be reached, the test plant was changed so as to apply a two-stage process where an enrichment of nitrifying bacteria in the second stage is expected.

The publicly sponsored tests carried out in France on a semi-technical scale showed that the efficiency of oxygen aeration can be increased by the availability of large amounts of sludge at high oxygen levels, since no deterioration of the physical characteristics of the sludge will occur and peak loads can be buffered adequately. The tests on wastes with sludge contents between 6 and 30 g/l demonstrated that with concentrations of mor than 10 g dried matter/l and thorough mixing, a significantly higher degree of oxygen utilization is achieved. The higher the pollution load, the more energy is saved. The process using pure industrial oxygen or oxygen enriched air can be employed at reasonable technical and financial expense. For these reasons, a pilot plant on technical scale was developed which should primarily be used for highly polluted wastes. The combination of the two-stage process with a flotation plant is particularly interesting. Advantages are expected when oxygen is used in the first biological stage and air in the second. Flotation is applied for thickening return and excess sludges of the first aeration stage.

The present and hitherto known results of research carried out in Europe, usually confirm the American results. Even if there are still certain variations with regard to individual test parameters due to locally differing starting conditions and differing objectives of the individual research activities, a uniform trend is noted which allows the following conclusions with regard to the practical application of the process:

1. The use of pure industrial oxygen or oxygen enriched air in the activated sludge process is possible without undue equipment requirements.

2. With the use of pure industrial oxygen, the degree of oxidizing agent utilization can be increased to more than 90 per cent.

3. Oxygen aeration allows a high oxygen content in the aeration tank which even with high sludge concentrations will contribute to maintain uniform reaction kinetics in the whole tank.

4. The increase in biomass in the aeration tank allows the use of smaller tanks.

5. The use of oxygen instead of air permits better and more economic adjustment to widely varying concentrations.

6. The availability of large amounts of sludge and easy adjustment to varying loads makes oxygen aeration a process particularly suitable for highly concentrated organic wastes with variable loads.

7. Waste water treatment using oxygen is carried out in closed systems, so that any nuisance due to the emission of odours and the contamination of the air with germs are prevented. Climatic implications, such as fog and ice formation, do not occur.

8. With the oxygen aeration process, the amount of waste gas produced is only about 1 per cent of that obtained with conventional compressed-air treatment, thus significantly facilitating odour control.

9. In case more stringent regulations with a view to environmental protection should make this necessary, undesirable components of the waste gas can easily be removed by thermic or catalytic oxygen aeration process.

10. In the light of present knowledge, the method for waste treatment using industrial oxygen or oxygen enriched air appears to be particularly suitable in the following cases:

    Wastes with high organic loads of varying concentration,

    Wastes with easily volatile components, tending to emit odours,

    Over-loading of existing plants, where the local conditions do not permit any extension of the area.

The encouraging results obtained so far, however, are set against a series of disadvantages and questions still to be answered which have to be reviewed for their technical and economic implications:

a) Are there any changes in reaction kinetics which cause any increased sludge activity when oxygen is used instead of air?

b) Are there any significant differences with regard to process technology between the use of cascade-type reactors, longitudinal flow reactors and thoroughly mixing reactors?

c) What is the optimum oxygen level in the aeration tank from the point of view of energy consumption?

d) Is it possible to estimate the increase in buffering capacity in the case of peak loads as against the conventional process?

e) Which changes with regard to process technology or additional facilities are required with the oxygen aeration process in order to achieve nitrification?

f) Under which conditions is it possible to combine oxygen aeration with physico-chemical stages for advanced waste treatment?

g) What is the ratio of excess sludge to BOD removal as compared with the standard process?

h) What are the changes in sludge characteristics observed with oxygen aeration and what are the technical and economic implications for subsequent sludge treatment?

i) What are the means and costs needed to meet the special requirements of the oxygen aeration process, such as increased safety precautions, protection against corrosion, gastight containers, etc.?

k) What are - on the basis of the conditions prevailing in Europe - the investment and operating costs of comparable plants using oxygen aeration and conventional aeration methods, respectively?

I should like to express the wish that the results and ideas of this workshop will contribute to find an answer to the open questions by cooperation of the European institutions concerned, and thus improve assessment and evaluation of the use of

oxygen in the biological waste treatment process. Additional expert talks on an international level will help to further the progress in this field.